MASS. CD1.2: F95

✓

UMASS/AMHERST
312066 0270 7612 8

Fuel Savings Achieved By "House Doctoring" and Storm Windows In Massachusetts Low-Income Homes: Final Report

Prepared by the Environmental Science Department of the Massachusetts Audubon Society

For the Office of Energy Conservation, Massachusetts Executive Office of Communities and Development, and the Office of Weatherization Assistance, U.S. Department of Energy.

November, 1986

GOVERNMENT DOCUMENTS
COLLECTION

OCT 6 1993

University of Massachusetts
Depository Copy

Massachusetts Audubon Society
South Great Road
Lincoln, Massachusetts 01773

EXECUTIVE OFFICE OF
COMMUNITIES & DEVELOPMENT
100 Cambridge Street
Boston, Massachusetts 02202

931/199

Fuel Savings Achieved By "House Doctoring" and Storm Windows In Massachusetts Low-Income Homes: Final Report

Steven Nadel and Mitchell Heineman
Environmental Science Department
Massachusetts Audubon Society
10 Juniper Road
Belmont, Mass. 02178

November, 1986

This project was a cooperative effort among staff at the Massachusetts Executive Office of Communities and Development (EOCD), the Massachusetts Audubon Society (MAS), and the eleven local agencies and 76 households who participated in the study. Thanks go to EOCD, MAS, and local agency staff including Brian Angus, Karen Bacas, Janet Baronian, Martin Betters, Ken Brown, Fred Clark, Bill Concannon, Pat Cronin, Charlie Delisle, Don Dunn, Lee Given, John Henry, Kelvin Keraga, Dave Lachowski, Al Mickee, Nighat Mohsin, Keith Murdoch, Daria O'Connor, Dawn Paul, Ken Rauseo, Rob Richard, Joe Schoolcraft, Brad Shea, Sally Sutherland, John Wells, and Mike York. Thanks also go to the designers and builders of our monitoring equipment: Larry Agi, Larry Kinney, and Paul Wankowitz. Special thanks go to Mike Sherman for coordinating EOCD's work on the project.

Massachusetts Audubon Society
South Great Road
Lincoln, Massachusetts 01773

EXECUTIVE OFFICE OF
COMMUNITIES & DEVELOPMENT
100 Cambridge Street
Boston, Massachusetts 02202

Contents

Summary..1
Introduction...2
    Massachusetts Audubon Fuel Savings Studies................2
    Reasons for this Study....................................2
    What is "House Doctoring"?................................3
Methodology..4
    Similarity with Previous Studies..........................4
    Selection of Study Homes..................................4
    New Methods in this Study.................................6
House Doctoring - Work Done................................8
    Agreement with Contractors................................8
    Contractors' Work...9
House Doctoring - Results.................................10
    Houses Selected..10
    Fuel Savings...10
    Infiltration Rates.......................................10
    Cost of Work...12
    Comparison with Other Studies............................12
Storm Windows...14
    Fuel Savings...14
    Cost...14
Control Group...14
    Savings..14
Economics...15
    Methodology..15
    Significance of this Data................................15
    Discussion...15
    Life Span..17
Other Findings..18
    Changes in Comfort and Drafts............................18
    Initial Infiltration, Infiltration Reduction and Fuel Savings...20
    Indoor Temperature Levels................................22
    Impact of Weather and Time of Year on Fuel Usage Data....24
    Analysis of Control Group Fuel Consumption Over Two Heating Seasons...27
Problems Encountered......................................29
    Locating Study Homes.....................................29
    Start-up Delays..30
    Troubleshooting..30
    Millivolt Heating Systems................................30
    Temperature Difference Accumulators......................30
    Attrition of Study Homes.................................31
    Blower Door Measurements.................................32
    Window Sash Sealing......................................32
Review of Methodology Changes.............................32
    Length of Monitoring Periods.............................32
    Transformers and Burner Timers...........................32
    Phone-in System..33
    Balance Point Adjustment.................................33

Digitized by the Internet Archive
in 2012 with funding from
Boston Library Consortium Member Libraries

http://archive.org/details/fuelsavingsachi00mass

Fuel Savings Using Alternative Analysis Methods....................33
Savings Analysis Using PRISM..34
    Methodology...34
    Applicability to this Study.....................................36
    Historical Fuel Records...36
    Data Analysis...36
    Attrition in the PRISM Sample...................................38
Conclusions and Recommendations.....................................38
    House Doctoring and Related Measures............................38
    Storm Windows...40
    Evaluation Method...40
Further Research Needed...41
Appendices
    A. Detailed Description of Analysis Methods.....................43
    B. Detailed Results...50
    C. Homes not Included in Final Sample...........................55
    D. Results of PRISM Data Search.................................56
    E. Questionnaires and Responses.................................58
    F. Additional Energy Savings Distribution Graphs................62
    G. Monthly Weather Tables December 1985 - March 1986............63
References..64

Figures

Figure 1. Agencies Participating in Study
Figure 2. Energy Savings Distributions
    A. House Doctor group
    B. Storm Window group
    C. Control group
Figure 3. Relationship between Fuel Savings and Infiltration Variables
    A. Fuel savings and infiltration reduction
    B. Fuel savings and initial infiltration
    C. Fuel savings and auditor's evaluation of house tightness
    D. Infiltration reduction and initial infiltration
Figure 4. Changes in Reported and Calculated Indoor Temperatures
Figure 5. Weather Trends December 1985 - March 1986.
    A. Degree days
    B. Cloud cover
    C. Wind speed
Figure 6. Savings Distribution in Two-Year Control Group
Figure 7. Savings Distribution for PRISM Housedoctor Homes

Tables

Table 1. Savings, Cost, Payback, and Benefit-Cost Ratio
Table 2. Changes in Comfort and Drafts
Table 3. Indoor Temperature Levels
Table 4. Comparison of Results Produced by Different Analysis Methods

Summary

The Massachusetts Audubon Society (MAS) conducted its third fuel savings study for the Massachusetts Executive Office of Communities and Development (EOCD) during the winter of 1985-86. While the studies of the two previous years had focused exclusively upon evaluating existing aspects of the Weatherization Assistance Program (WAP) and other conservation programs operated by EOCD, this study analyzed storm windows, a current WAP component, and also investigated "house doctoring", an innovative weatherization technique that EOCD wished to determine how best to incorporate into its programs (for this study house doctoring was defined as the use of a blower door and other instruments to locate hidden heat leaks in a building, and the sealing of these leaks).

MAS, working with 11 local program operators, analyzed fuel consumption patterns in households across Massachusetts using on-site monitoring instruments. Using an improved version of the method used in its previous studies, MAS determined fuel savings due to weatherization in just a few months, so that EOCD was able to evaluate the results less than a year after the study began. The study found that:

* House doctoring, while cost effective, has a lower benefit-cost ratio than EOCD's WAP program. House doctoring cut space heating fuel use an average of 8.9% and had a simple payback period of approximately eight years. However, some aspects of house doctoring are probably more cost-effective. It would be better to integrate the essential strategies of house doctoring into WAP than to rely upon the few practitioners who provide full house doctoring services.

* Storm windows are cost-effective if one assumes at least a seven year useful lifespan. Storm windows reduced space heating fuel consumption an average of 9.6% and had a simple payback period of over six years. Since storm windows are often used improperly, it is better to assign them a low priority in weatherization programs, except where it is critical that a primary window be protected by a storm window.

MAS also analyzed its data using several different analysis techniques including the Princeton Scorekeeping Method (PRISM), which has been used in other fuel savings studies. These investigations showed that the MAS method is well suited to studies where it is desirable to obtain results quickly, as in evaluating pilot programs, and to studies on oil-heated homes, where long-term fuel usage records are often inadequate or unavailable.

Introduction

Massachusetts Audubon Fuel Savings Studies

For the past three years, the Massachusetts Audubon Society (MAS) has conducted fuel savings studies of the weatherization programs administered by the Massachusetts Executive Office of Communities and Development (EOCD)[1]. During the winter of 1983-84, MAS analyzed fuel savings in fifteen Massachusetts households that took part in the Weatherization Assistance Program (WAP). Using on-site monitoring instruments and data collected by workers at local agencies, MAS determined the fuel savings due to weatherization over the course of one heating season. In contrast to other fuel savings analysis methods, which may take over a year before results can be obtained, the MAS technique provided EOCD with savings figures shortly after the conclusion of the heating season.

During the winter of 1984-85, MAS studied a number of EOCD's weatherization programs, and determined fuel savings and benefit-cost ratios for several program components. The study showed that some long standing assumptions about weatherization did not make economic sense. While caulking and weatherstripping were key elements of most weatherization programs, these measures were shown to have low benefit-cost ratios (the lifetime savings due to these measures were only slightly higher than their cost). At the same time, a high cost measure such as oil burner replacement was shown to have a very high benefit-cost ratio.

Reasons for this Study

Upon considering the results of this study, MAS and EOCD agreed that it would be worthwhile to conduct a similar study during the winter of 1985-86 on two weatherization strategies: storm windows and "house doctoring" (a new alternative to conventional caulking and weatherstripping with higher potential energy savings).

For years, EOCD has included storm windows among the components of its weatherization programs. However, little data was available to indicate the actual fuel savings value of this costly improvement. By analyzing the savings attributable to storm windows, EOCD hoped to establish more firmly the place of storm windows on its priority list for weatherization programs.

---

[1] EOCD dubbed the latter two studies "BirdWAP", playing upon the initials of the program being evaluated (the Weatherization Assistance Program) and the common asssociation of MAS with birds.

What is "House Doctoring"?

"House doctoring" is an approach to energy analysis and retrofit originally developed at Princeton University. In the 1970's, researchers at Princeton and other research centers discovered that much of a building's heat loss occurs through numerous obscure passageways, such as through foundation cracks, around chimneys, and through plumbing chases. These researchers developed and refined different techniques to reduce these heat flows and to attack other instances of energy waste. These techniques were soon combined with new energy analysis procedures to produce the "house doctor approach" to weatherization. In its pure form, "house doctoring" involves:

1. Diagnosis of a house using special equipment such as a "blower door" (a door with a powerful fan which increases airflow through hidden passageways, making them easier to spot), infrared camera, and a heating system combustion analyzer. This diagnosis is used to locate air infiltration sites, thermal bypasses (places where heat moves around insulation), convective loops (cyclical air movement patterns that bring cold air into a house and pull warm air away) and heating system inefficiencies.

2. Remedying of simple problems through the application of sealants, weatherstripping and small amounts of insulation, and through basic adjustments to heating and hot water systems.

3. Prescription of additional major weatherization measures (such as attic insulation or a burner replacement) to take place after the "house doctor" has left.

The basic concepts of "house doctoring" have been extensively described by others (see for example Harrje, et. al., 1980 and Diamond et. al., 1982).

For this study, since EOCD already incorporated basic heating and hot water system improvements and major weatherization measures into its programs, MAS and EOCD decided to examine only the air infiltration, thermal bypass and convective loop aspects of "house doctoring". Specifically, this study sought to examine the heating energy savings and cost-effectiveness of these aspects of house doctoring and to determine how these aspects might best be incorporated into the EOCD weatherization programs. Therefore, throughout this paper, we will refer to "house doctors" and "house doctoring" (hereafter without quotation marks) as the contractors and the technologies that seek to reduce heat waste in buildings through reducing air infiltration rates, thermal bypasses, and convective loops using blower doors and other diagnostic and sealing equipment.

Methodology

Similarity with Previous Studies

The current study utilized a modified version of the same methodology employed in both of the previous BirdWAP studies. As in the earlier programs, each study home received two monitoring instruments, a fuel burner run-time meter, and an electronic temperature difference accumulator (TDA).[2] The run-time meter measured the hours of operation of the home's heating system,[3] and the TDA measured the cumulative degree hours difference between indoor and outdoor temperatures. Using data from these instruments, MAS could determine each home's fuel usage rate adjusted for changes in indoor and outdoor temperature. The difference between a home's initial fuel usage rate and the rate observed after the home received weatherization treatment is a measurement of the fuel savings attributable to the treatment. Other components of the study included questionnaires that addressed clients' energy use patterns, use of local weather data, and testing of the results using T-test, analysis of variance (ANOVA), and linear regression statistical procedures. See Appendix A for a detailed description of the methodology.

Selection of Study Homes

During October and November 1985, EOCD and MAS located eleven local program operators that were interested in participating in the study, five of which had taken part in the previous year's program (denoted by an asterisk). These agencies were:

1. Action for Boston Community Development (ABCD)
2. *Berkshire Community Action Council (BCAC)
3. Citizens for Citizens (CFC)
4. *Franklin Community Action Corporation (FCAC)
5. *Greater Lawrence Community Action Council (GLCAC)
6. Housing Allowance Project (HAP)
7. Menotomy Weatherization Program (Menotomy)
8. Montachusett Opportunity Council (MOC)
9. *North Shore Community Action Program (NSCAP)
10. *Somerville Office of Planning and Community Development (Somerville)
11. South Middlesex Opportunity Council (SMOC)

Agency service areas are indicated in Figure 1.

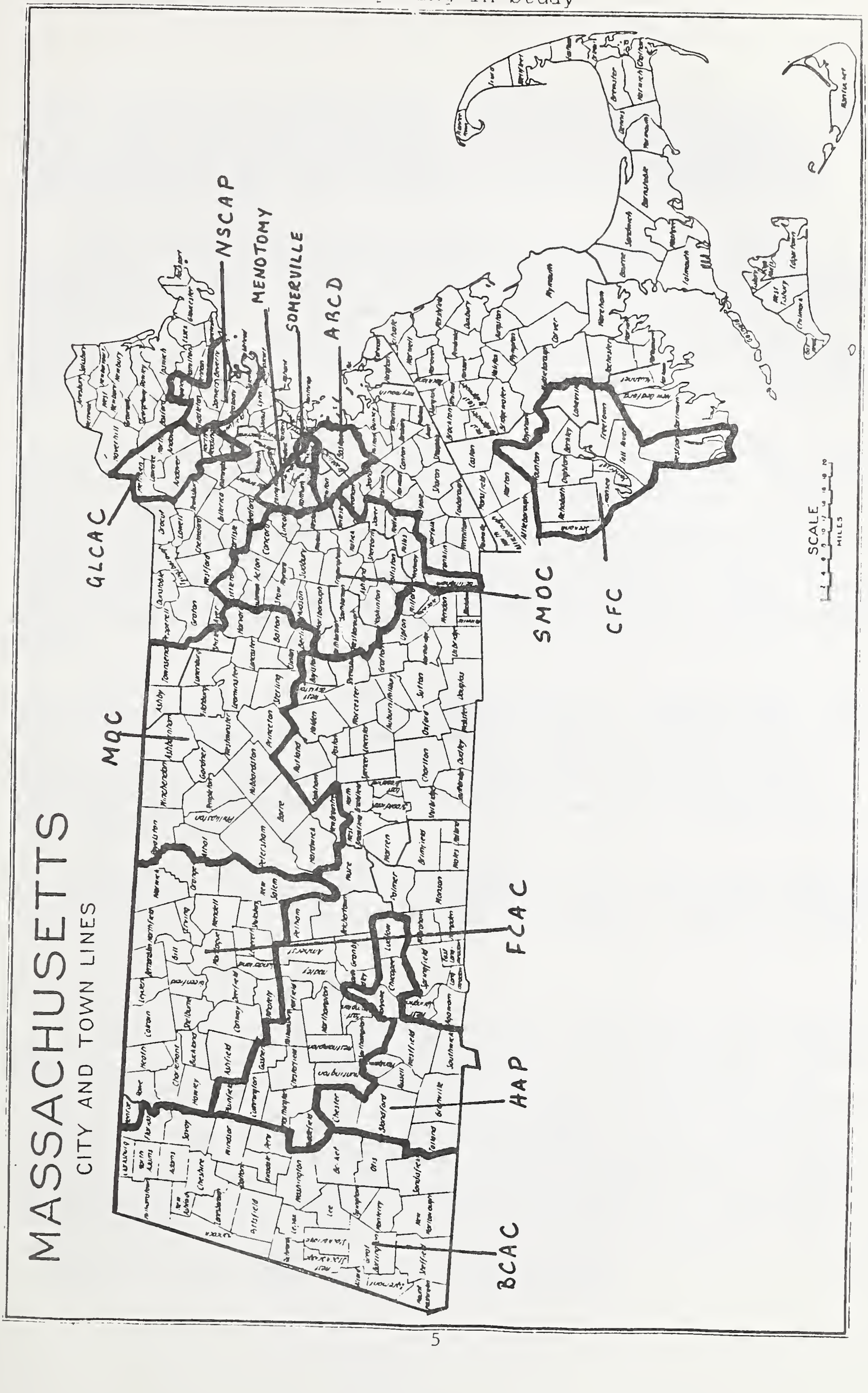
MAS originally planned to locate one hundred study homes among current and former WAP applicants at participating local program operators. These were to include forty house doctor

---

[2] The TDAs were designed, built, and maintained by Paul Wankowitz, Research Design.

[3] Burner run-time multiplied by the fuel input rate yields actual fuel consumption. See Nadel (1984a) for a discussion of this relationship.

Figure 1. Agencies Participating in Study



units, forty storm window units, and twenty control units. Houses were sought that were heated primarily by a central heating system, did not obtain domestic hot water from their central heating system, and were willing to cooperate throughout the sixteen week study.

Only one and two family homes were selected for house doctoring. Triple deckers were not included due to the complexity of monitoring these homes, and since MAS was also conducting a concurrent study of house doctoring in this housing type (in cooperation with a separate state agency). In the case of two family homes, since the house doctor contractor would need to work on the entire house, we sought homes where both units could be monitored.

Homes for the storm window group were initially sought from among one, two, and three family residences where the study unit had few or no storm windows (or double glazed windows). When it became apparent that few such homes could be located, the guidelines were amended to include previously weatherized homes without storm windows, and homes that had storms on some, but fewer than a quarter, of their windows. Funding for these homes came exclusively from state funds since the federal weatherization program does not generally fund work on previously weatherized homes.

Control homes were sought principally from among homes that had participated in the 1984-5 BirdWAP study. MAS believed that it would be impractical to ask current WAP applicants to agree to have the weatherization work in their homes postponed until spring for the sake of the study. Previous study participants represented a pool of over thirty homes that were already known to meet the study criteria.

Characteristics of homes included in the study are summarized in Appendix E. In general, the characteristics of houses included in the BirdWAP study compare closely to houses served by the WAP program.4

New Methods in this Study

The primary differences between this study and its immediate predecessor were the number and length of study periods. Whereas last year's study included four one-month study periods in a single heating season, this study consisted of just two periods -- a baseline period that ran from mid-December through the end of January (or even into February in some cases), and a follow-up period that began in February and extended through March. The agencies welcomed the simplified system; and the longer periods meant that MAS could expect to gather more data for each house, increasing the statistical significance of the results.

---

[4] Sherman, Mike, EOCD, personal communication.

The monitoring equipment was also modified to simplify work for both the agencies and the clients in the study homes. In the earlier studies, oil-heated homes had been equipped with run-time meters that ran directly off those systems' household voltage. To avoid the costly measure of running electrical cable (meeting building code requirements for 115 volt transmission) from the basement to the living space, the meters had been attached directly to the furnace or boiler. This year, in order that the meters might be located in more accessible areas, MAS provided 24 volt transformers, so that the meters could be placed in the client's living space, since building code requirements for 24 volt transmission are less stringent than for 115 volt currents. Thermostat wire was run from the transformer, which was installed at the furnace, to the meter, which was commonly placed directly atop the TDA. These same transformers also allowed us to connect run-time meters to millivolt gas systems.[5] In last year's study, these homes could only be monitored at the gas meter, which often included energy usage of other appliances.

With the meters easily accessible, clients could report weekly meter readings to the agencies on a weekly basis via telephone at a pre-arranged time. This eliminated the need for the time consuming weekly site visits agency workers had made to each home in the earlier studies. Agency personnel were instructed to check with clients at the time of the weekly phone call to make sure the meters were still working, and were also expected to calculate the fuel usage rate for the week in order to detect any unusual events and identify faulty instruments.

The control group was a feature of this study that MAS had been unable to include in the previous years. As in any experiment, the results are open to question unless the researchers can demonstrate that their results are due to the parameters being studied, and not extraneous factors. MAS hoped that by including a group of homes that received no weatherization treatment during the study, any other factors that might influence fuel savings in study households might be identified.

The fuel usage rates calculated this year were adjusted to reflect research that has shown that the "balance point" in most homes is about 60°F (Fels, 1985). Internal heat gains in a home, such as people, lights, and appliances, help heat a house. The balance point is the outdoor temperature at which a home's internal heat gains raise the indoor temperature to a level where ideal indoor temperature is maintained without input from a heating system. Some of the indoor-outdoor temperature difference measured by the TDAs is due to internal heat gains. This heat, since it is not produced by the heating system, does not belong in a calculation of weather-adjusted fuel use. Weather adjusted fuel

---

[5] The millivolt/24 volt/115 volt transformers were designed by Larry Kinney of Synertech Systems and built by Republic Controls.

calculations should be based on the difference between outdoor temperatures and a home's balance point. To estimate this temperature difference, we subtracted 8^{o}F per hour from the TDA readings (68^{o} assumed average indoor temperature minus 60^{o}F assumed balance point[6]).

A final change was improved data analysis software. For last year's study, MAS had written its own data management and analysis programs in BASIC. This year we used a microcomputer database management system (dBase III) which simplified data entry and analysis.

House Doctoring - Work Done

MAS selected three contractors to do the house doctoring work. We chose three contractors (as opposed to one or two) in order to have enough contractors that the work could be done quickly (within a two to three week period) and to get a sense of style and savings variations between contractors. We limited the number of contractors to three in order simplify program administration and keep sample sizes large enough that statistical analysis of results could be attempted for each contractor.

Agreement with Contractors

MAS gave each selected house doctor contractor the same instructions about the work desired. The guidelines specified that the contractor should make thermal boundary improvements to each client's home, striving to reduce air infiltration in each home by 40% as measured at 50 Pascals of pressure (approximately equivalent to the pressure exerted by a 30-40 mph wind exerted on all sides of a house[7]) but not to reduce the air infiltration rate below 6 air changes per hour at 50 Pascals. These figures were determined from recommendations made by the contractors.[8] Contractors were asked to measure infiltration rates using a calibrated blower door, and to submit a report indicating infiltration rates at the start and completion of work.

The primary contractor selected, contractor #1, had been employed in other low-income weatherization studies in New York and Pennsylvania (see Rodberg, 1984, and Commission on Economic

---

[6] Average indoor temperature was estimated at 68^{o} F based on the results of a survey of homeowners undertaken as part of the 1984-85 BirdWAP study (Nadel, Meyer and Granda, 1986).

[7] Lou Gougeon, Retrotec Weatherization Services, personal communication.

[8] The 40% figure was suggested by Retrotec Weatherization Services based on specifications developed by the U.S. Air Force, while the 6 air changes per hour was recommended by Princeton Energy Partners.

Opportunity, 1985).[9] Half of the homes were allotted to contractor #1, while the others were divided between contractor #2 and contractor #3 (both Massachusetts-based companies). Billing rates for the work were set at $900 per single family home and $1,600 per two family home for contractor #1, and $0.45 per square foot of heated living space for each of the Massachusetts contractors. Contractor #1 informed us that they would also have charged us $0.45 per square foot had they been performing in-state work.

Contractors' Work

With a crew of two, contractor #1 devoted one work day to each home they were assigned. Upon arrival they set up their blower door and pressurized the home. With the door fan operating continuously, they inspected the house with the aid of an infrared scanner and usually began work in the attic. Their work emphasized caulking and foaming (with a urethane foam spray) bypasses and openings along a home's thermal boundary. Much of their attention was devoted to attics, and often included considerable re-engineering of attic access hatches and doors. Basements received treatments similar to attics, while living spaces were a lower priority. Their approach has been thoroughly documented by Bliss (1984).

While contractor #2 performed much of the same work as contractor #1 on bypasses and openings in attics, basements, and living spaces, the outward appearance of their work was entirely different. Their crew of three typically took two days to complete weatherization in each household (albeit on considerably larger houses). Following an initial blower door test and inspection with a smoke stick (a device that produces a mist that helps identify air currents), contractor #2 dismantled the blower door and set to work. Unlike contractor #1, they weatherstripped windows and doors and caulked baseboards throughout the living space. Their work in attics and basements did not differ substantially from contractor #1's. The blower door was only set up again when most of the work was completed. Their approach closely follows methods described in Energy, Mines, and Resources Canada (1984).

Contractor #3 employed an approach similar to contractor #2. However, contractor #3 also used a different method for obtaining blower door readings. This factor, and resulting complications, resulted in contractor #3 completing work on too few houses for us to accurately portray their work in this report. See the "Problems Encountered" section for a discussion of this issue.

---

[9] This contractor objected to our use of the term "house doctoring" for the work we solicited, as they prefer to reserve its use for the comprehensive approach mentioned earlier (see What is "House Doctoring"?). Most of the actual project work was performed by a franchisee based in New York state.

House Doctoring - Results

Houses Selected

In order to simplify travel and contractual arrangements for the house doctors, most agencies were initially assigned one contractor. Contractor #1 worked on twenty-one houses, contractor #2 serviced nine homes, and contractor #3 serviced five. Twenty-nine units are included in the final sample.

Fuel Savings

Mean fuel savings among house doctor homes was 8.9 ± 7.6%. (This figure, and all subsequent fuel savings reported in this paper are reported with 95% confidence intervals.[10]) The median savings for the group was 6.0%. Mean savings for the eleven contractor #2 and contractor #3 houses were 11.2 ± 8.8%, with a median of 11.2%. Mean savings for the eighteen contractor #1 homes were 7.5 ± 7.3%, with a median of 5.1%. While the difference in fuel savings between the two groups is statistically insignificant (at the 95% confidence level), the energy savings distribution graph for house doctoring (Figure 2A) illustrates that there are distinct differences in savings achieved by each contractor. Half (9 among 18) of the contractor #1 houses experienced savings of less than 5%, while more than half (6 of 11) of the the contractor #2 and contractor #3 homes experienced savings greater than 10%.

The range of savings measured in individual homes did not vary much among the contractors. The maximum savings observed in a house doctor home was 25.6%, and the minimum savings was -0.4%, these both in contractor #1 units. Minimum and maximum savings in contractor #2 and contractor #3 homes were both within five percentage points of these extremes. See Appendix B.1 for a listing of fuel savings and confidence intervals for individual homes.

Infiltration Rates

Infiltration rates measured by the contractors varied considerably. Initial tests by the house doctors showed average infiltration rates (air changes per hour at 50 Pascals) of 17.0 in contractor #1 homes, 13.5 in contractor #2 homes, and 19.5 in

---

[10] A confidence interval is a range around the mean of a sample, marking the limits within which the mean would fall, for a given probability level, if the sample were infinitely large. For example, in this study a 95% confidence interval was constructed around the mean fuel savings: the mean house doctor savings was 8.9 ± 7.6%. This means that there is a 95% chance that the mean of an infinitely large sample will be between 1.3% and 16.5%.

Figure 2. Energy Savings Distributions

Figure 2A. House Doctor Group

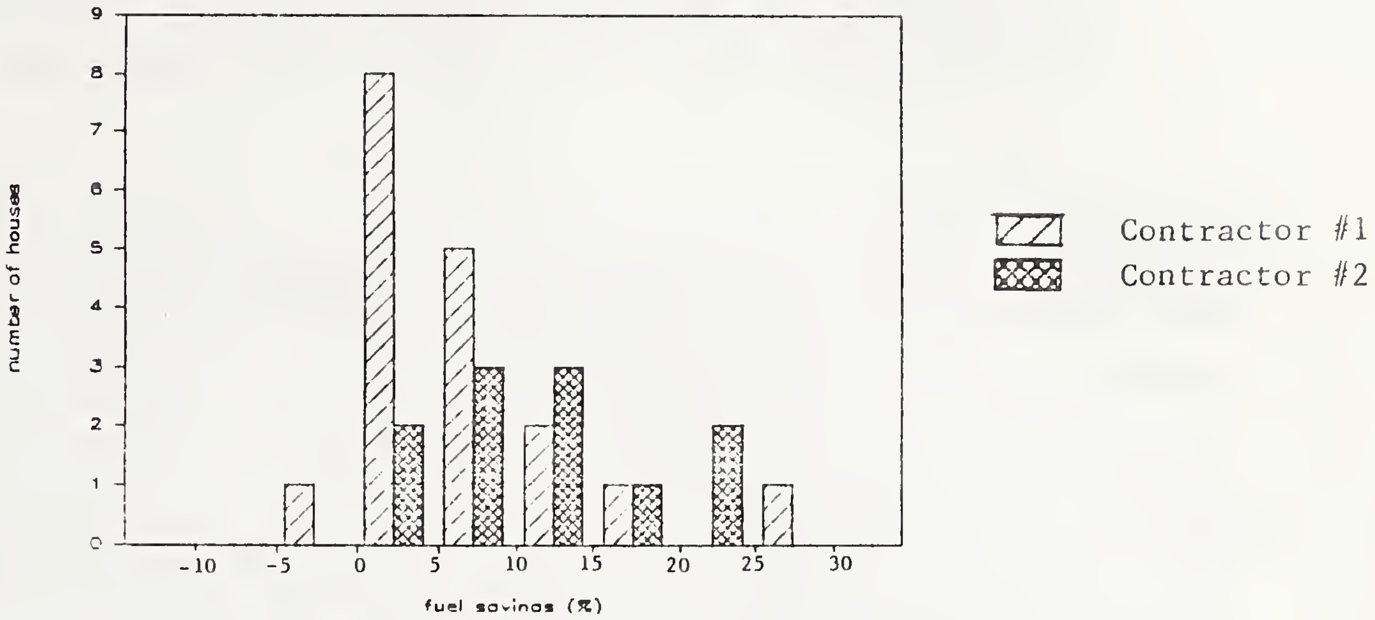


Figure 2B. Storm Window Group

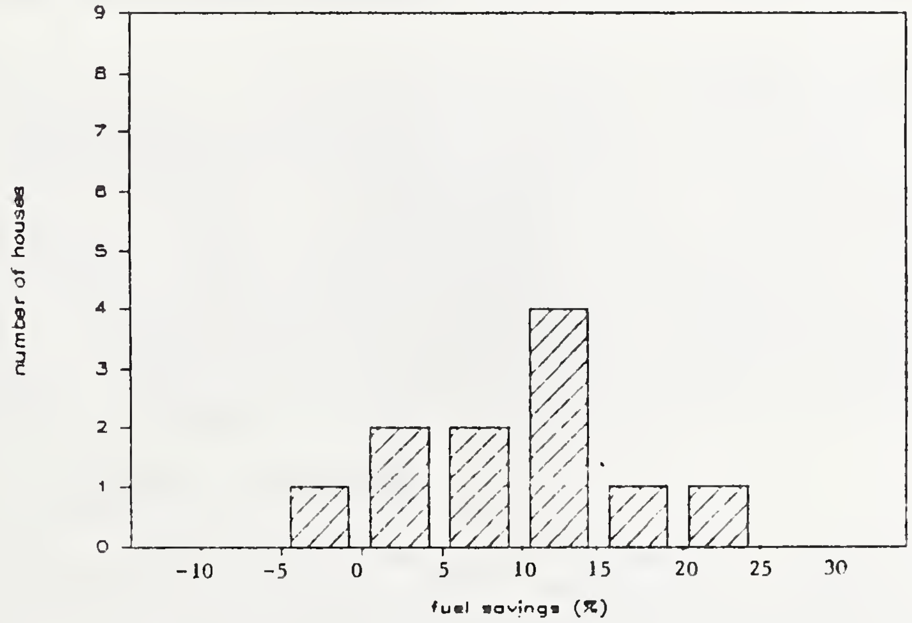
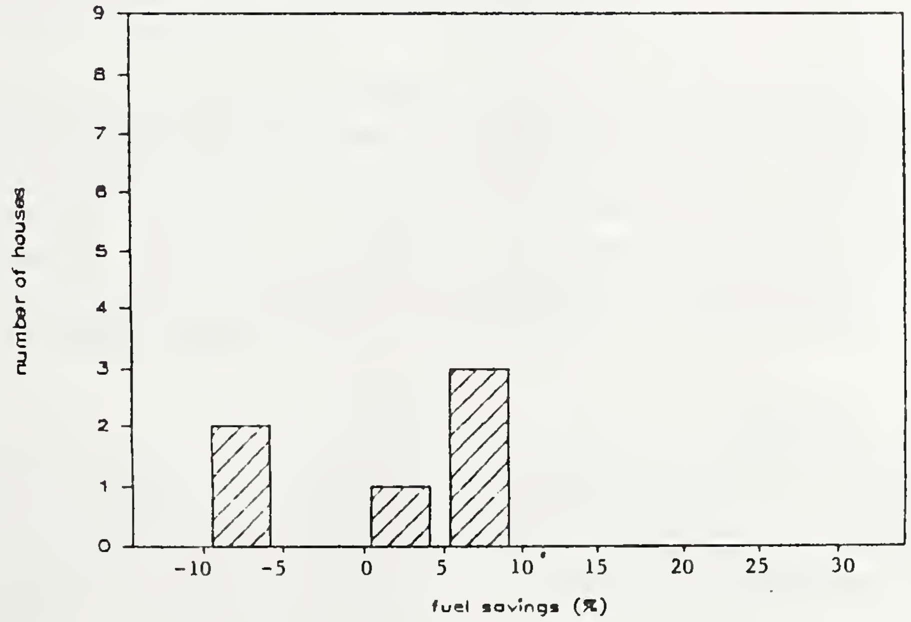


Figure 2C. Control Group



contractor #3 homes. Improvements in infiltration rates averaged 21% for contractor #1, 33% for contractor #2, and 17% for contractor #3. As we will discuss later in the section "Other Findings," these data bear little relation to fuel savings figures.

Cost of Work

As mentioned earlier, billing rates for the house doctor work were set at $0.45 per square foot of conditioned living space for contractor #2 and contractor #3, while contractor #1 charged $900 per single family home, and $1,600 per two-family home. Contractor #2 charged $830 on average in the eight single family homes they worked on. This figure includes work for which contractor #2 submitted separate bills (as in an instance where they installed a vapor barrier over a suspended ceiling that had no permanent ceiling above it). The house doctor contractors used square footage estimates based upon the total area occupied by a building. These figures are generally about 20% greater than the interior floor area measurements the community agencies obtained for us.

The three house doctor contractors charged an average of $827 per unit. In order to make comparisons among the contractors' work and evaluate the cost effectiveness of house doctoring, we believe it is necessary to compensate for the difference between our square footage estimates and the contractors' estimates, and to consider contractor #1's work as if they had charged in-state rates. Thus, in the analysis of house doctoring that follows in the "Economics" section, we have determined prices based on 120% of the interior square footages the agencies measured.

Comparison with Other Studies

The results of this study are consistent with the results of other studies on house doctoring. However, comparisons between studies are difficult to make because of differences in house doctoring techniques employed, and differences in the type, age and condition of houses being studied.

We know of only two other studies which look at the energy savings attributable to the infiltration, thermal bypass and convective loop aspects of house doctoring. These studies report savings similar to or less than the savings measured in the BirdWAP study. However, both of these studies were on middle-class houses in the Pacific Northwest, a housing stock considerably different from the houses included in the BirdWAP study.

Dickinson, et al. (1982a) report an average reduction in heating energy use of 9.2% in a sample of 17 houses which received 22 person-hours of house doctoring. They also report 0% average heating energy savings in a sample of 20 houses which received only 10 person-hours of house doctoring. However,

changes in energy use patterns resulting from high tenant turnover in the 10 person-hour homes may have masked any savings that were achieved in these homes.

Engels and Peach (1985) report a reduction in total energy use of 10% in 55 houses that received "super-weatherization" and house doctoring. Conventional caulking and weatherstripping was included in the super-weatherization package. In comparison, savings averaged 10% and 14% in two groups of 58 and 59 homes which received only super-weatherization. Their study found that the difference in energy savings between house doctoring (as practiced in their study) and conventional caulking and weatherstripping was negligible.

Several studies have looked at the energy savings from full house doctoring which included work on water and space heating systems in addition to infiltration, thermal bypass, and convective loop work. These studies analyze total primary fuel use (total use of the fuel used for space heating, usually including energy used for water heating and cooking, and sometimes including energy used for appliances and lighting). However, if we estimate that space heating accounts for two-thirds of the primary energy use in the BirdWAP study homes, then the 8.9% average space heating savings translates into the equivalent of approximately 6% primary fuel savings.

In general, using this approximation, the studies on full house doctoring in low-income housing show higher savings than was found in the BirdWAP study, implying that simple work on space and water heating systems produce additional energy savings.

For example, Commission on Economic Opportunity (1985) estimated house doctoring work cut primary fuel consumption by 17% in 40 homes served by the WAP program. Preliminary monitoring data on seven houses indicates approximately 13% savings. Quaid, et al. (1986) report primary fuel savings of of 7.4% in a group of low-income single-family homes which were house doctored as part of a pilot weatherization program in Minneapolis. Rodberg (1986) reports average primary fuel savings of 20.2% in a group of New York City single-family and row houses which received house doctoring and additional weatherization (primarily window improvements). Savings in a group of homes receiving weatherization only were 2.5% Median savings were 13.4% and 1.5% respectively, implying that savings due to house doctoring were approximately 12-18%.

Studies on full house doctoring in newer, middle-income housing stock show somewhat lesser savings than were measured in the BirdWAP study and other studies on house doctoring in low income housing. Dutt et al. (1985) report 15.3% primary fuel savings in a sample of suburban New Jersey and New York homes served by a pilot house doctoring project. Savings in a control group of unweatherized houses were 9.8%, making for net savings due to house doctoring of 5.5%. Dutt (personal communication)

estimates that approximately 75% of these savings were due to heating and hot water system improvements. Similary, O'Regan, et al. (1982) report net primary fuel savings of 4.5-4.7% due to house doctoring in a group of suburban houses in Walnut Creek, California.

Storm Windows

Fuel Savings

Unfortunately, this already small study group experienced heavy attrition. Twelve homes were dropped from an initial sample of twenty-three (see the "Problems Encountered" section, page 28). Fuel savings in the eleven homes in the final sample ranged from -0.5% to 20.6%. The mean savings was 9.6 ± 9.6% and the median for the group was 10.8%. Although the sample is small, it does exhibit a bell-shaped curve about its mean, (See Figure 2B, page 12), indicating that this is a normally distributed group.

Cost

The number of storm windows installed varied considerably between homes. At ABCD, one of the participating local program operators, quantities ranged from eight to as many as twenty-one windows per home, and averaged sixteen windows per home. The costs for the windows at this agency were $48 for windows with a bare aluminum finish ($33 materials, $15 labor), $55 for windows with a baked-enamel finish ($38 and $17) and $43 per deadlight[11] ($30 and $13). Among the eleven homes in the final sample, the average total cost was $720.

Control Group

Savings

Of the sixteen homes initially selected for this study group, only six homes could be included in the final sample (see the "Problems Encountered" section for an explanation). Savings in this group ranged from -9.1% to 9.4%, with mean savings of 2.0 ± 8.7% and a median (of limited significance for such a small sample) of 4.5%. The energy savings distribution graph (Figure 2C, page 12) shows that this sample is too small to indicate a normally distributed population. Despite the small sample size, the low savings measured in this group indicate that in all likelihood the study results were not appreciably affected by any systematic differences between the pre- and post-weatherization periods.

---

[11] A deadlight is a fixed-pane storm, usually placed over a stationary window, such as a picture window.

Economics

Methodology

Annual heating fuel use was estimated for each house by calculating pre-weatherization fuel consumption per degree-day (base 60) and multiplying these figures by 5500 degree days (which is approximately the average for Massachusetts at a base of 60o).[12] Annual heating costs were estimated for each house by multiplying estimated annual fuel use by average Massachusetts fuel costs during the 1985-86 heating season ($1 per gallon of oil and $.70 per therm of natural gas).[13] Post-weatherization heating fuel use and costs were estimated in a similar manner and savings due to weatherization calculated for each house and for the mean of all houses receiving a particular weatherization treatment. These figures, along with average cost, simple payback period, estimated useful lifetime, and benefit-cost ratio for each weatherization technique examined in this study are reported in Table 1. The benefit-cost ratio shows how many times a weatherization measure will pay back its initial cost in fuel savings over its useful lifetime. It is valuable for comparing the relative benefits of treatments with different lifetimes.[14] For comparison purposes, data on several of the weatherization measures examined in last year's BirdWAP study (Nadel, Meyer, and Granda, 1986) are also included.

Significance of this Data

Since these data are based on only two months of monitoring data and include significant differences among groups in house size and initial energy efficiency (as measured in units of energy consumed per square foot of living space per degree day) these economic figures should be considered approximate rather than definitive.

Discussion

As can be seen in Table 1, house doctoring is cost-effective (benefit-cost ratio greater than one), but its benefit-cost ratio is lower than the benefit-cost ratio for the full package of measures installed through EOCD's basic or complete WAP program. While house doctoring saves more energy and probably lasts longer than standard caulking and weatherstripping, house doctoring also costs considerably more. Overall, the benefit-cost ratio for

---

[12] Degree days (base 60, 30 year average) for BirdWAP towns range from 4630 for Fall River, MA to 6725 for Greenfield, MA. The average for the 11 BirdWAP towns is 5519. Degree day data supplied by New England Weather Science, Quincy, MA.

[13] MAS estimate based on surveys conducted by the Massachusetts Executive Office of Energy Resources.

[14] Benefit-cost ratio is calculated by multiplying annual dollar savings by estimated measure lifetime and dividing by initial cost.

Table 1. Savings, cost, payback, and benefit-cost ratio of house doctoring, storm windows, and other weatherization measures.

Measures	Sample Size	Savings (%)	Annual Savings ($)[a]	Avg. Cost	Simple Payback (yrs)	Est. Lifet (yrs)[b]	Benefit Cost Ratio[c]
House Doctoring	29	8.9	$ 72	$ 584[d]	8.1	10-15	1.2-1.8
Storm Windows	11	9.6	119	720	6.1	10-15	1.7-2.5
Control group	6	2.0	2	0	-	-	-
WAP: basic[e]	47	21.2	197	1160	5.9	15	2.5
WAP: complete[e]	21	28.4	264	1413	5.4	15	2.8
Std. caulking, weatherstripping, and minor repairs	18	7.2	67	225	3.5	5	1.5
Rope caulk & plastic storm windows	29	11	102	65	.7	1.5	2.2

Notes:

a. Annual savings for the house doctoring, storm window and control groups were calculated for each house and for the mean of all houses. For the other measures, annual savings were estimated by multiplying the percent savings times an average fuel bill of $928 (which was the average fuel bill at 5500 degree days for the house doctor and storm window houses). Given large differences in average annual fuel bills between houses in this year's and last year's study, we felt that direct comparison of this year's and last year's fuel bill figures would be misleading.

b. Lifetimes were estimated by MAS in consultation with MEOCD staff.

c. Benefit-cost ratios were calculated by multiplying annual savings by the estimated average lifetime of the weatherization measure(s) and dividing by the cost of the measure(s).

d. Both Retrotec and EMC charged $0.45 per square foot of conditioned space. PEP charged more due to travel and lodging costs for crews to come from out-of-state. For these calculations, their standard in-state price of $0.45 per square foot was used.

e. "WAP: basic" denotes the basic Weatherization Assistance Program (WAP) as practiced in Massachusetts during the 1984-85 heating season. "WAP: complete" denotes a subsample of last year's study in which additional funds were made available so weatherization priorities (including heating system improvements, attic and sidewall insulation, and standard caulking, weatherstripping and minor repairs) could be completed. Recent changes to the Massachusetts WAP guidelines have made the 1985-86 Massachusetts WAP program nearly identical to the scope of work studied under "WAP: complete."

house doctoring (as studied in this project) and standard caulking and weatherstripping are similar.

It should be noted that the benefit-cost ratio for rope caulk and plastic storm windows (including initial installation costs and assuming 50% of the materials are reused a second year) is higher than the ratio for either house doctoring or standard caulking and weatherstripping, although not as high as the ratio for the overall WAP program.

Other house doctoring approaches may be more cost-effective than the approach studied in this project. For example, if other weatherization services, such as basic heating system adjustments, are done by the house doctors during the same visit, travel and setup costs would be split among the different services, making each measure more cost-effective. Costs of house doctoring could also be lowered if house doctors spent less time in each house and concentrated on only major gaps, leaks, and bypasses. The Sun Power Consumer Association in Colorado is experimenting with this approach; preliminary results indicate high cost-effectiveness (John Proctor, Sun Power Consumer Association, personal communication).

Storm windows have a benefit-cost ratio higher than house doctoring but probably lower than the overall WAP program. However, these economic figures assume that storm windows will always be used correctly. Site visits by MAS and EOCD staff have found that some improper use and deterioration can be expected, so benefit-cost ratios will probably be lower. Storm windows can also have other benefits besides direct energy savings. For example, weatherization program operators often install storm windows where a primary window is starting to deteriorate but does not yet warrant replacement. The storm window thus protects and extends the life of the primary window, saving energy and major maintenance expenses. We did not attempt to quantify the value of this benefit.

Life Span

While a storm window may increase the lifetime of a primary window by protecting it, the storm itself is then subject to the environment, and may degrade rapidly under adverse conditions. The large, unsupported panes are subject to breakage through mishandling, the seals may deteriorate, the frames may break, or the occupants may forget to or be unable to close the storm windows. We may expect the useful life of a storm window in low-income housing to be lower than among the general population due to factors such as greater proportions of elderly clients who might have trouble operating the windows, shorter tenant occupancies resulting in less attention to property maintenance, and lower quality housing stock and accompanying poorer quality of window frames into which storm windows are installed. MAS estimates the useful life of a storm window in low-income housing at ten to fifteen years.

House doctoring is subject to vagaries of a different sort. While the weatherization materials installed often have undisturbed lives of 20 years or more, the materials can be disturbed, shortening their life. For example, the materials installed may be subsequently destroyed by a contractor, such as a plumber who needs to work on a pipe that the house doctor has surrounded with sealing materials. In one home that had been recently house doctored (not in this study), we observed a large gap around several water pipes where a plumber had ripped out the styrofoam and urethane that the house doctor had installed. These materials are also prone to depradation by squirrels, and other pests that can damage weatherization work.

Contractor #2 and contractor #3 both weatherstripped windows and doors in many homes. While the materials they used for this work were of very high quality, any weatherstripping has a limited lifetime due to the considerable wear it receives. We know of no study that has attempted to determine the useful lives of most weatherization measures. Overall, we estimate the useful life span of house doctoring work at ten to fifteen years. This estimate is identical to an estimate made by Dutt et al. (1985), but somewhat longer than the eight year lifetime estimated by Quaid et al. (1986).

Other Findings

Changes in Comfort and Drafts

At the end of each study period, clients were asked to evaluate their homes' comfort and draft levels using a four point scale (see Table 2). At the end of the baseline period, clients in the study homes generally felt that their homes were "fairly comfortable" but "somewhat drafty". There were differences among groups, though. Clients in the storm window and contractor #2 houses reported lower comfort and higher draft levels than did clients in the other groups. This may indicate that these larger houses were also in poorer overall condition. Contractor #1 clients reported higher comfort levels and lower draft ratings than their counterparts in the contractor #2 homes. This may show that these were generally smaller houses.in better condition than the others in the study (these houses generally had lower initial infiltration rates). Clients in the control homes, which were all weatherized in 1985, reported the highest comfort and lowest draft levels of any of the groups.

Following the weatherization treatments, many clients found marked improvements. More than half the storm window recipients (9 of 14) reported comfort improvements of at least one increment on our 4 point scale and all but one storm window recipient (out of 14 responses) reported draft reductions of at least one increment. Based on a Wilcoxin statistical test, we can say with

Table 2. Changes in Comfort and Drafts

Group	Comfort Improvement -1	0	+1	+2	+3	Draft Reductions -1	0	+1	+2	+3
House Doctor	3	19	6	2	0	1	11	10	7	2
Contractor 1	2	12	4	0	0	1	7	7	4	0
Contractor 2	1	4	1	2	0	0	2	2	3	2
Storm Window	0	5	8	1	0	0	1	7	5	1
Control	1	7	1	0	0	0	6	2	0	0

Key: +2 represents a 2 notch improvement, as from "fairly uncomfortable" to "very comfortable" on the comfort scale

Comfort Levels Reported by Study Participants

Group	Pre-treatment VU	FU	FC	VC	Post-treatment VU	FU	FC	VC
House Doctor	0	2	20	8	0	0	17	13
Contractor 1	0	0	13	5	0	0	11	7
Contractor 2	0	2	3	3	0	0	3	5
Storm Window	1	3	7	3	0	0	6	8
Control	0	0	3	6	0	0	3	6

Key: VU - very uncomfortable FU - fairly uncomfortable
FC - fairly comfortable VC - very comfortable

Draft Levels Reported by Study Participants

Group	Pre-treatment VD	SD	LD	ND	Post-treatment VD	SD	LD	ND
House Doctor	9	12	6	5	0	6	13	13
Contractor 1	3	9	5	2	0	6	6	7
Contractor 2	5	2	0	2	0	0	5	4
Storm Window	6	3	4	1	0	2	4	8
Control	0	2	5	1	0	1	5	2

Key: VD - very drafty SD - somewhat drafty
LD - a little drafty ND - not drafty

99% confidence that comfort increased and drafts decreased in storm window homes.

More than half the contractor #2 clients (5 of 9) reported draft reductions of at least two increments on our four point scale, and 78% reported draft reductions of at least one increment. Comfort improvements were reported in 3 of 8 contractor #2 homes and a comfort decrease was reported in one home. Based on statistical analysis of this data, we can say with 99% confidence that drafts decreased in contractor #2 homes, and with 80% confidence that comfort increased in these homes.

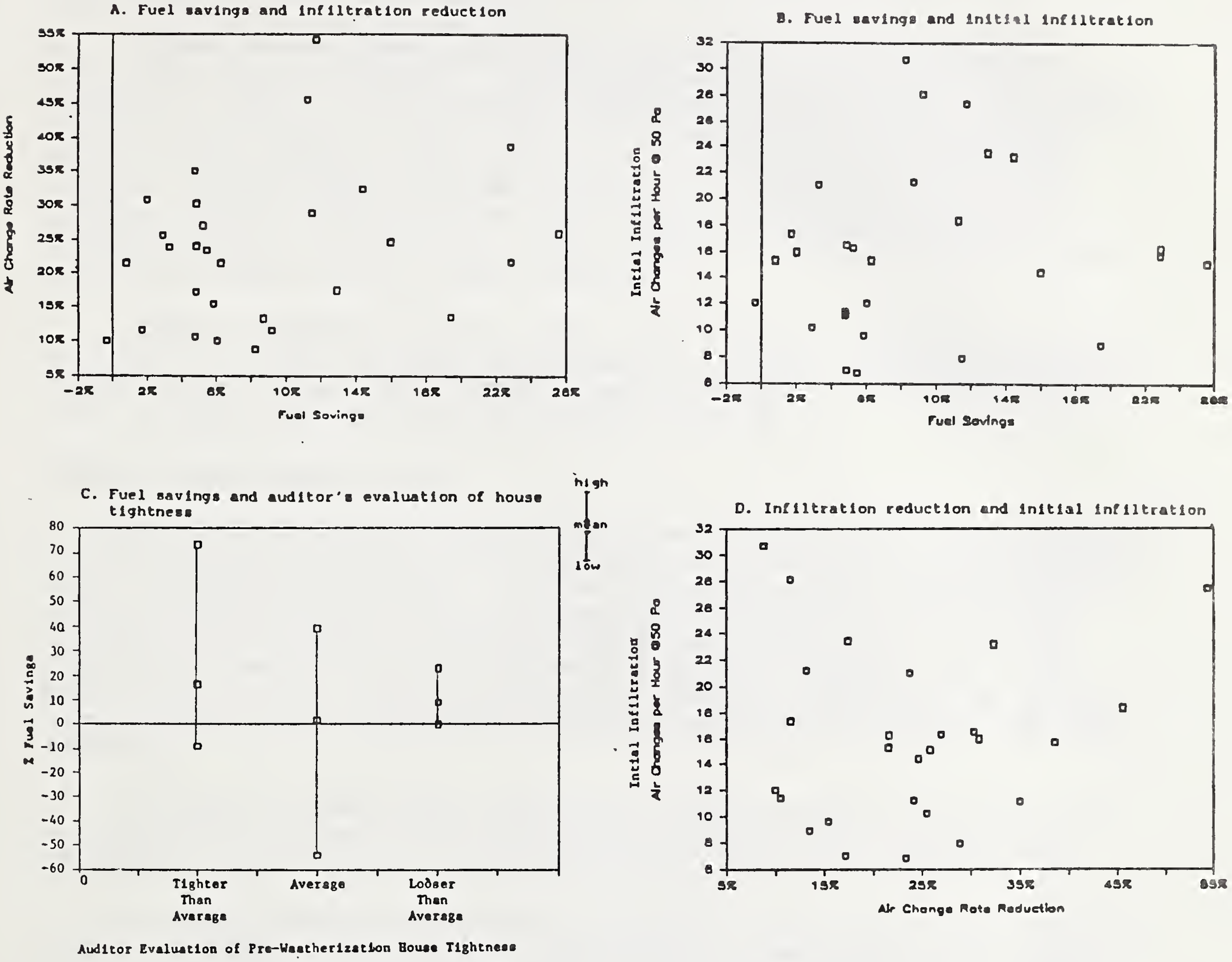
Lesser improvements were reported by contractor #1 clients, although the differences between contractor #1 and contractor #2 homes are not statistically significant. Contractor #1 clients reported draft reductions of at least one increment in 58% of the homes. Comfort improvements of at least one increment were reported by 4 of 18 contractor #1 clients and 2 of 18 clients reported a one increment decrease in comfort level. Based on a Wilcoxin statistical test, we can say with 90% confidence that drafts decreased in contractor #1 homes. Comfort improvements in contractor #1 homes were not statistically significant at the 80% level. Differences between contractor #1 and contractor #2 homes may be due to the fact that contractor #1 homes were in better condition, leaving less room for comfort and draft improvements. These differences can also be due to the fact that contractor #2, unlike contractor #1, spent considerable time sealing air leaks in the living space, resulting in noticeable comfort and draft improvements.

Comfort and draft levels in the control group remained essentially unchanged between the pre- and post-weatherization periods. At least 75% of the control group residents reported no change in comfort and draft levels. Draft decreases were reported in 2 of 8 homes. A comfort increase was reported in one home and a comfort decrease was reported in another.

Initial Infiltration, Infiltration Reduction, and Fuel Savings

The blower door is central to the house doctor's craft. House doctors often use blower door readings to report on the effectiveness of infiltration reduction work and to estimate fuel savings. We, therefore, would expect to find a correlation between the infiltration reduction data that the contractors reported to us and the fuel savings we observed, even though this phenomenon is diminished by sealing thermal bypasses and convective loops, which save fuel but do not affect blower door readings. We would also expect to find a relationship between the initial infiltration rates (either measured with a blower door or estimated by an energy auditor) and the fuel savings achieved, since it is presumably easier to reduce infiltration in a leaky house rather than in an already tight one. However, our findings show no relationship between fuel savings and either initial infiltration or infiltration reduction (see Figure 3). There was also no relationship between initial infiltration and the

Figure 3. Relationship between Fuel Savings and Infiltration Variables



infiltration reduction achieved. Each of the above relationships exhibited an r-squared (correlation coefficient) below six percent, meaning that over 90% of the variance in the data is not explained by the relationship.

Other researchers have found a similar lack of patterns. Dickinson et al. (1982b), in their summary of two house doctoring projects, report that "[w]hile significant reductions in leakage areas (up to 35% in some groups) were observed, corresponding reductions in energy use were not." In the same vein, Rodberg (1986), in his study on house doctoring in New York City low income housing, reports that "the energy savings were not significantly correlated with the reductions in air infiltration which the house doctor teams achieved."

These findings indicate that infiltration reduction is a poor indicator of fuel savings performance, and that pre-screening to locate houses that will benefit most from house doctoring based upon initial infiltration has minimal value.

Indoor Temperature Levels

We studied indoor temperature levels using two techniques; at the end of each monitoring period, clients were asked to report their thermostat settings, and we estimated indoor temperature levels using weather station data and readings from the TDAs. Although most clients reported different settings for the two monitoring periods, the study-wide averages changed little for both the reported and the calculated figures. However, as Table 3 shows, there was a systematic difference between the two sets of readings.

Although we have used different sample sizes to obtain the two data sets, there is a difference of about 5oF between the calculated and reported temperature levels.

We hypothesize that these differences are due to two factors. First, reported temperatures are based on thermostat settings while calculated temperatures are based on a temperature sensor placed in a room of average temperatures (TDA installers were explicitly told to avoid placing sensors in rooms that were particularly warm or cold). Since standard practice is to install thermostats in the cool parts of the living space, temperature by the thermostat is likely to be several degrees colder than a home's average temperature.

Second, calculated temperatures were computed by adding average indoor-outdoor temperature difference (measured by the TDA) and average outdoor temperature (from a nearby weather station). To the extent temperatures at the weather station are higher than temperatures by the TDA outdoor sensor, calculated indoor temperature estimates will be too high. Since weather stations are often located at airports (moderate weather patterns

Table 3. Indoor Temperature Levels

(o Fahrenheit)

	Reported			Calculated		
Group	pre	post	##	pre	post	##
All	67	66	52	72	72	38
Control	65	65	8	69	69	6
Storm Window	68	67	13	76	75	6
House Doctor	67	67	31	72	72	26
Contractor 1	67	67	18	72	72	17
Contractor 2	66	66	9	70	71	6

are one factor in airport siting decisions),15 and since TDA outdoor sensors were usually placed on the north side of buildings (to keep the sensors from being exposed to direct sunlight), we would expect many cases in which weather station temperatures were higher than temperatures by TDA outdoor sensors, causing calculated indoor temperatures to be exaggerated.

Changes between the pre- and post- treatment periods are less evident. Average reported temperatures declined slightly for the second period, but only the storm window group showed a decline in both reported and calculated temperatures. This disparity is evident in Figure 4, which shows a plot of changes in reported and calculated indoor temperatures for twenty-two houses for which full data was available. The graph shows that although a majority of this group (13 of 22) reported lower temperatures for the post-treatment period, only half of that majority (7 of 13) actually registered lower temperatures on the temperature accumulators. In addition, most of the changes are very small and none of the changes are statistically significant. We must conclude that there was no appreciable change in thermostat settings for our study groups.

Impact of Weather and Time of Year on Fuel Usage Data

Both the 1983-4 and 1984-5 BirdWAP studies included extensive investigation of the effects of solar heat gain, wind speed, and extremes of temperature on the fuel usage rates measured. The only noteworthy finding of these queries was that a very cold January in 1985 resulted in a slight increase in fuel usage per degree hour temperature difference in some homes. This year, we once again collected information on daily cloud cover and wind speed at each of the localities in our study.

Overall, Massachusetts experienced very steady weather during the winter of 1985-6. The weather graphs in Figure 5 and the weather tables in Appendix G show that average temperatures across the state changed little from December through late March. Only during a brief spell in late January, and again at the end of March did weekly average temperatures rise above forty degrees, and at no time did weekly average temperatures drop below twenty-two degrees anywhere in the study area.

When the temperature did vary, wind and sun usually moderated any influence on our data these changes might have had. December was slightly cloudier than the other months; January was somewhat windier; and February was cloudier and colder, but less windy. March was both warmer and sunnier, so we might expect fuel usage rates to decline somewhat as the solar heat raised indoor temperatures. However, the sun is higher in the sky in March, so it does not provide as much heat gain through vertical windows,

---

15Howard Brown, President, Resource Planning & Management, New Haven, CT, personal communication.

Figure 4. Changes in Reported and Calculated Indoor Temperatures

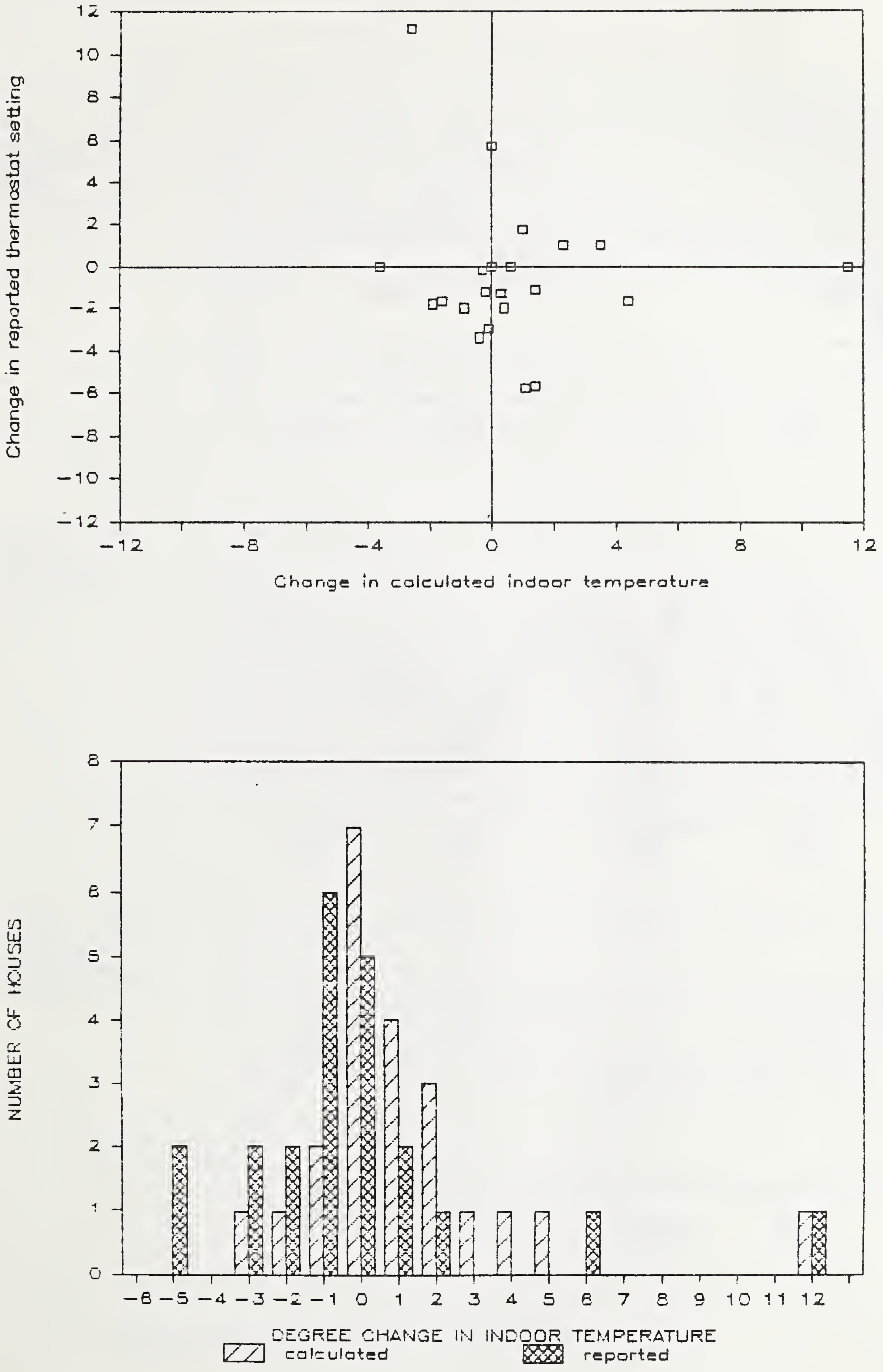
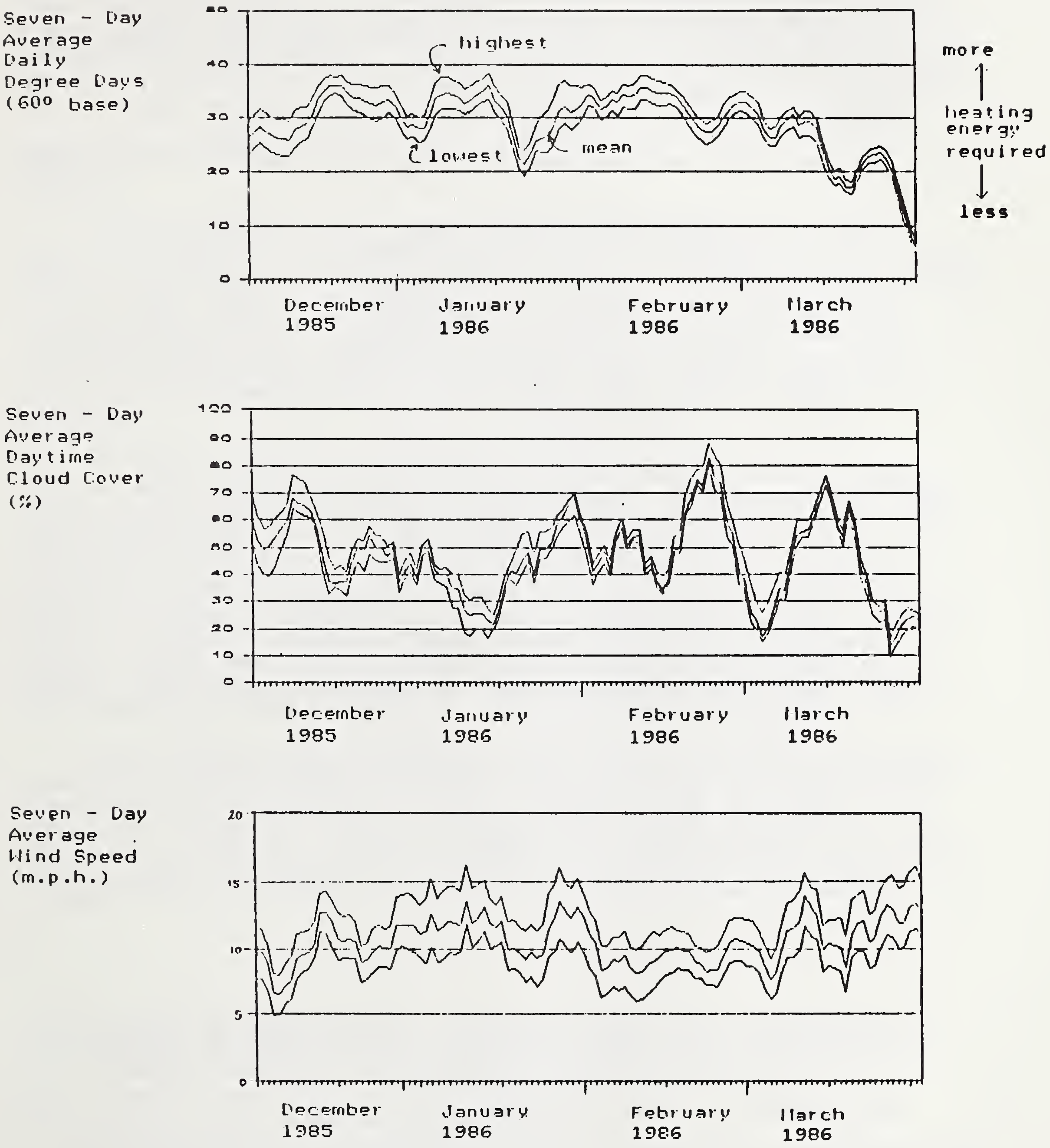


Figure 5. Weather Trends December 1985 - March 1986



Source: New England Weather Service

causing less indoor warming.[16] While we have not analyzed the data closely, there appears to be a slight rise in fuel usage rates in late March. We hypothesize that people may have become less stingy with their thermostats when they saw an early end to the heating season approaching and might have opened their windows to let some fresh air in, likewise letting their heat out.[17] The balancing effects of these various phenomena lead us to believe that weather did not significantly bias our savings results.

Analysis of Control Group Fuel Consumption Over Two Heating Seasons

In an attempt to get some information on whether energy savings achieved by the WAP program maintain themselves over time, and in an attempt to examine fuel use rates as measured by the MAS method, over two heating seasons, we compared fuel consumption rates in the 1985-86 BirdWAP study control group with the post-weatherization fuel consumption of these same homes as studied in the 1984-85 BirdWAP study. Due to the small size of the control group, we only had data on eight houses to include in this analysis.

In these houses, fuel consumption per degree-hour increased in five cases and decreased in three cases. In five out of eight cases, fuel consumption rates in 1985-86 were within 10% of the consumption rates in 1984-85. Among all eight houses, fuel consumption increased an average of 3.4% ± 14% (95% confidence interval). The distribution of savings achieved in individual houses is shown in Figure 6. Given the small sample size and the large confidence interval, these results are not definitive. However, they indicate that WAP fuel savings do not deteriorate rapidly (WAP program savings in these homes averaged 28%), but that some slow deterioration of savings may be occurring.

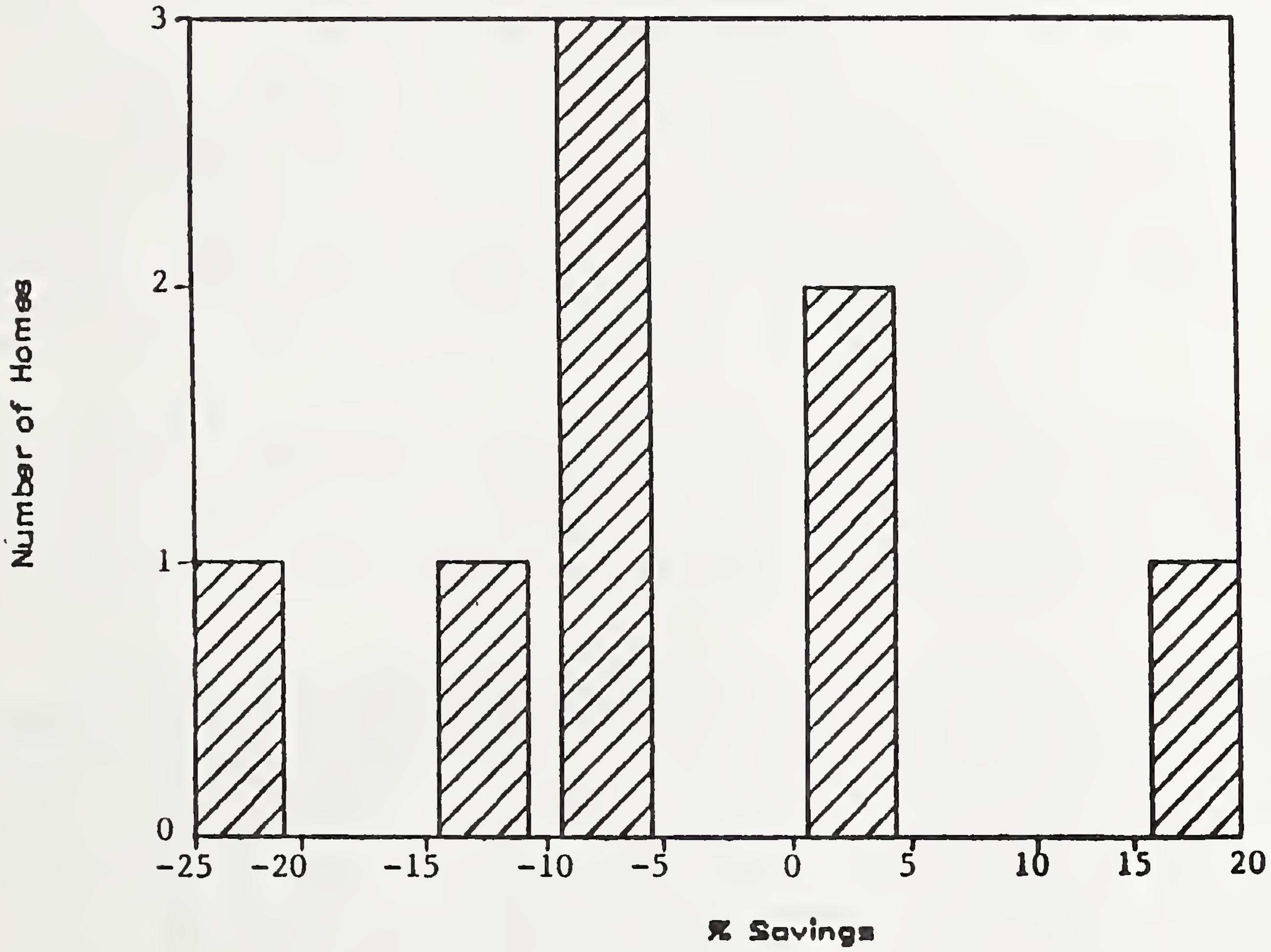
This analysis also indicates that, when groups of houses are examined, fuel consumption rates, as measured by the MAS method, appear to be fairly stable. There appears to be no large systematic difference in fuel consumption rates between the spring 1985, and the winter 1985-86 periods. Further analysis on a larger sample of houses is needed before definitive statements can be made.

---

[16] According to ASHRAE solar insolation data (as summarized by Anderson and Riordan, 1976, p. 60), at 40° north latitude, a square foot of vertical south facing glazing receives approximately 1728 Btu of clear day insolation in January and February, but only 1484 Btu in March.

[17] The hypothesis of a springtime rise in thermostat settings runs counter to the findings of Kempton et al. (1984) who, based on an intensive study of seven homes in Michigan, report that households often lower their thermostats in the spring.

Figure 6. Savings Distribution in Two-Year Control Group



Problems Encountered

Locating Study Homes

Since seven agencies participating in last year's study had located eighty-four study homes, we did not contemplate that eleven agencies might be unable to identify one hundred homes for this study. However, numerous obstacles prevented us from reaching the desired number of houses. Several of the agencies do not currently process large numbers of WAP applications and also have high proportions of homes that have major secondary heat sources, disqualifying them from participation in the study. Also, there was limited incentive for agencies to seek study homes: while some of the clients would receive special services, the study represented additional workload for the agency, as well as delayed completion of weatherization work in the client's home. EOCD allocated funds for each agency to hire extra staff or have existing staff take on the added duties, but these funds went largely untouched because many agencies found it easier to have existing staff do the work than to hire and train new staff. Instead, the study became a favor that the agencies were doing for EOCD, and MAS was left with little leverage with already overworked and overextended agency personnel.

Agencies seeking homes for the control group faced the additional problem of asking people to contribute their time without receiving any return. Not only were some of the participants from last year's study unwilling to take part again, but numerous others were unavailable because they had moved away or died.

While EOCD knew that many agencies installed considerable numbers of storm windows, they had not realized that a high proportion of these windows were either replacements or were on homes that already had storms on most of their other windows. When the requirements were changed to include prior WAP participants, only two agencies were able to locate substantial numbers of homes, several of which were of marginal value to the study. The homes that were selected for this group were from the "bottom of the barrel": in searching for homes without storm windows, the agencies located physically deteriorated housing. These homes had a higher rate of problems, such as tenants moving and non-cooperative landlords and tenants, than other homes in the study.

The house doctor homes were much easier to locate than the other homes, since the only specific constraint beyond the basic study parameters was that they should only include one- and two-family homes. In the case of two-family homes, we wanted to monitor both units, since the house doctor work affected and involved both units. Misunderstandings between MAS and the agencies led to delayed installation of monitoring equipment in the second unit of these two-family homes and in one instance,

rather than connect the second unit of a two-family home, the agency terminated monitoring in the first.

Start-up Delays

Late installation of monitoring equipment in the second unit of two-family homes was not the only factor that delayed the study. At one agency, only one home was monitored before Christmas because the staff member working on the study was hospitalized for much of December. Otherwise, the main obstacle to timely commencement of monitoring was the three week average lapse between delivery of the meters to the agencies in late November and their installation.

Troubleshooting

Problems in study homes were located in four ways: clients were requested to report obvious problems to the agencies; agencies were asked to check all data for inconsistencies as it came in; agencies were asked to frequently forward data to MAS for review; and MAS conducted occasional site visits. Due to the large number of agencies involved, MAS remained unaware of most problems until several weeks had passed, by which time the only remaining option often was to eliminate a house from the study. While some agencies were adept at locating trouble before much data was lost, others were unable to identify these problems, especially where meters still ran, but at abnormal rates. Numerous homes were initially wired so that their run-time meters ran continuously: agency personnel did not recognize that these data indicated a serious problem. Similarly, many agency personnel could not determine whether or not a client's reported reading was clearly wrong or not. MAS was able to decipher a few readings where digits were reversed or decimal points were misplaced, but in some cases entire datasets were lost.

Millivolt Heating Systems

The twenty-four volt transformers we supplied to the agencies were designed to function with either 115 volt oil systems or millivolt gas systems. Power to run the timer for millivolt systems was supplied through a standard three-prong electrical cord that connected directly to the transformer. While the technicians had little trouble wiring the timers to oil systems, problems wiring millivolt systems led to the elimination of several homes from the study. Those that were wired successfully nevertheless ran in "reverse"; when the heating system was off, the timers ran, and when the system was on they stopped. These readings often proved difficult for agency personnel to interpret.

Temperature Difference Accumulators

While in most homes the TDAs functioned flawlessly, we were unable to use TDA data in the majority of contractor #2 and storm

window homes. Although we instructed the agencies to inspect the placement of the TDA sensors following weatherization work, TDA data for the follow-up period were lost because either sensors were cut by the contractors, the outdoor sensor was placed between the primary and storm window, or the sensors were disconnected from the TDAs. We suspect that several agencies failed to inform the contractors about the TDAs, and that they also did not inspect the installations following weatherization. In most instances, the agencies did not recognize that data were erratic; when the sensors were cut or disconnected, the accumulator registered double or triple its normal tally, and TDAs with sensors in windows still registered about half their normal accumulations. Only in the rare instance when an accumulator broke down completely and ran at a frenetic pace or ceased to register did some agency personnel identify malfunctioning units. In instances where TDA data was not usable, we substituted degree-day information from a nearby weather station.

Attrition of Study Homes

Both the storm window and control groups suffered considerable attrition, the latter to the point where its results cannot be considered conclusive. Attrition caused larger confidence intervals around the results, but the remaining homes still provide meaningful results. However, had everyone devoted closer attention to the study, up to nineteen more homes might have remained in our sample. At one agency, five control homes were disconnected at the end of January because the agency thought that control homes did not need to be monitored during the follow-up period. However, it is not clear if the clients involved would have cooperated through the rest of the study, as they were unanimously opposed to permitting the equipment to be re-installed when the situation was recognized a few days later. Some problems with clients occurred at almost every agency. One client cooperated just long enough to get storm windows installed. Similar problems occurred elsewhere where clients were unable to read their meters accurately, or simply could not be reached via telephone.

In the few homes where run-meters failed, agencies were able to install replacements quickly. Problems with TDAs, as discussed above, were not so readily recognized. Three homes had to be eliminated due to equipment failure. Two of these homes' TDAs were broken during weatherization, and changes in lifestyle between the two monitoring periods meant that fuel usage rates based exclusively upon weather station data were highly irregular. In the first, a client living alone got a job during the follow-up period, and thus was no longer home days. In the second home, the client lost his job, and was home days only during the second period. In the third home where equipment failure was the primary problem, the run meter ceased to operate a few weeks after house doctor work was completed. We were not sure that it had functioned properly in the preceding weeks, and eliminated the house.

Blower Door Measurements

We observed significant differences in blower door measurements among the house doctor contractors. This was probably due to both differing techniques and instruments. Contractor #3 employed a different measurement protocol than the other two contractors, which produced significantly lower values than contractor #1 and contractor #2 obtained.[18] Differences among practitioners mean that it is best to only compare data for the same contractor. In future studies, strict instructions regarding measurement methods should make such comparisons possible.

Window Sash Sealing

Both contractor #2 and contractor #3 sealed upper window sashes and unused windows as a weatherization technique. While we do not dispute the fuel savings value of this process, we believe that its practice should be limited. While the contractors routinely consulted residents before they undertook this procedure, residents might later regret such a step, and local agencies and building inspectors might frown on such a practice. We suggest that where sash sealing is deemed beneficial, contractors should use a removable product, such as "zip-seal" or rope caulk.

Review of Methodology Changes

As discussed in the Methodology section, there were four principal features of the methodology of this study that had not been used in the previous MAS studies:

Length of Monitoring Periods

The longer study periods generally meant that more data could be gathered, and more accurate (better confidence intervals) results obtained. In houses where clients were unavailable for part of a monitoring period, we were able to use a few observations spread over a longer time span. Such homes would have been dropped using the older method.

Transformers and Burner Timers

Except for the problems with metering millivolt systems, the transformers were a success. No transformers malfunctioned, nor

---

[18] Contractor #3 sealed "intentional openings" (chimneys, dryer vents, etc.) before taking blower door measurements. They also included unheated basements in infiltration calculations. These adjustments make a house's air infiltration characteristics different from the way they are under "normal" circumstances. For this reason, we recommend that in future studies contractors be instructed not to make these adjustments.

were any problems encountered connecting the transformers to oil heating systems. The transformers enabled us to place the run-time meters in the living space with the temperature accumulators. In previous years, millivolt systems could not be metered directly (gas meters readings were used instead) and oil systems were monitored using a higher voltage timer that was attached directly to the oil burner.

Phone-in System

Having the clients read the meters to the agency workers over the phone greatly reduced the time the agencies had to devote to data acquisition. While there were a few problems with clients who misreported readings, clients were generally cooperative. Many clients kept their own weekly data sheets, and read the meters on a regular basis even when contact with the agency lapsed (such as if the client wasn't home when the agency called, or the agency worker was not available). However, this system also meant that agency workers could devote less attention to the project, and thus were less likely to notice equipment problems. As discussed above, much data was lost because of meters that were unplugged and/or broken.

Balance Point Adjustment

The balance point adjustment involved subtracting eight units per hour from the TDA readings. Since all of our data was processed using a computer, this process was quite simple, and as discussed previously, we believe it produced more accurate results.

Fuel Savings Using Alternative Analysis Methods

Many other fuel consumption studies rely exclusively upon temperature data obtained from weather stations, and many studies analyze fuel consumption data with regression equations (treating fuel consumption as a function of degree-days). We compared our results with results from these different methods. We analyzed savings using our "mean ratio method" (comparing the mean ratio of fuel consumption per degree hour during the pre-weatherization period to the mean ratio during the post-weatherization period) but only using weather station data, we performed regression analyses using the TDA data, and we used only weather station data to perform a second set of regression analyses. Each analysis method is described more fully in Appendix A.

We also computed average fuel savings using each analysis method. In order to facilitate comparisons among these data, we only included homes where sufficient data was available for inclusion in each group. Since this reduced our sample considerably, we only computed these figures for twenty-one houses in the house doctor group. Using TDA data with the mean ratio method, we found savings of 9.1 ± 7.3%. Mean-ratio savings using

weather station data averaged 8.1 ± 8.1%. Using a regression analysis, we obtained savings of 9.9% using TDA data, and 7.7% with weather station data only.

In order to discern patterns in our data, we determined the average difference between savings figures obtained using each method, as well as the average of the absolute value of the differences. The former calculation shows which method produced greater savings figures, while the latter shows the similarity of the results between the methods. The regression figures are limited to houses with at least four data points (five meter readings encompassing four monitoring periods), while the TDA figures include only those homes that passed a T-test. This data is summarized in Table 4.

We believe that these results demonstrate the soundness and usefulness of the mean-ratio method using TDA data. Without TDA data, savings figures are slightly lower and have higher confidence intervals.[19] The regression method, which produced results nearly identical to the mean-ratio method, can only be used with larger data sets,[20] and requires analysis techniques which are difficult for the non-statistician to understand. An advantage of the mean-ratio method is that many agency workers can grasp the method readily; some agency workers in our study were able to make preliminary savings estimates after just one or two weeks of post-treatment data were gathered.

Savings Analysis Using PRISM

Methodology

PRISM, the PRInceton Scorekeeping Method for determining fuel usage rates in households, has often been used in other studies to analyze fuel savings attributable to weatherization programs (Fels, 1985, etc.). The method normally involves analyzing fuel

---

[19] Higher confidence intervals are probably due to the fact that the TDA data captures site-specific indoor and outdoor temperature information which is inherently a more accurate predictor of fuel consumption than outdoor temperature data from a weather station miles away from a house. The difference in fuel savings we cannot explain. We had hypothesized that households increased their indoor temperature levels after weatherization, reducing savings calculated with degree-day data, but not affecting savings calculated with TDA data (TDA data captures changes in indoor temperature, degree-day data does not). However, as is discussed in the "Other Findings" section, indoor temperatures did not change between the pre- and post-weatherization periods.

[20] While six to eight weeks of data is desirable for both the mean-ratio and regression methods, the mean-ratio method can be used with as few as two data points, while the regression method requires a minimum of four data points.

Table 4. Comparison of Results Produced by Different Analysis Methods

	Average Difference	Average Absolute Difference	
TDA - Deg.hr.			
Mean Ratio	0.6%	3.9%	(28 homes)
Regression	1.1%	4.3%	(28 homes)
Mean Ratio - Regression			
TDA	-0.1%	1.4%	(29 homes)
Deg.hr.	0.2%	1.8%	(38 homes)

consumption data for at least one year prior to and following treatment. It does not rely upon on-site metering, but instead utilizes fuel dealer or utility company records. For this study we tried to apply short-term PRISM-based techniques, using one year of historical fuel records to determine baseline fuel usage, and our post-treatment run-time meter readings for the follow-up data. Next spring, MAS plans to carry out full PRISM analyses on several homes when sufficient post-treatment data is available.

Applicability to this Study

The nature of our study limits its applicability to PRISM. Since most of the storm window and control homes were weatherized during 1985, we can only utilize fuel data from after the date of weatherization, as we would expect that fuel usage rates were altered by the weatherization work. The house doctor homes, while they are appropriate for the short-term PRISM discussed above, will not provide useful data for full PRISM analysis next fall, as they were all weatherized following the conclusion of our follow-up period (April-May 1986).

Historical Fuel Records

Historical fuel consumption records were sought for 66 study homes; monitoring in the other 10 homes had been terminated due to evictions, other weatherization work, and similar problems. Four oil-heated homes were found to have no regular fuel dealer, and a fifth home was occupied by a new tenant. Among the remaining sixty-one homes, we made contact with 55 clients' fuel dealers.

While records for some oil-heated homes appear to be useful, eight homes were serviced by C.O.D. (cash on delivery) dealers who maintain no historical records, five homes were serviced by oil and gas companies who did not maintain meter reading and delivery data information, four clients regularly received deliveries of fifty or one hundred gallons instead of tank fill-ups, two clients changed fuel dealers during 1985, and two clients had only two fill-ups or meter readings during 1985. None of these groups can be included in a PRISM analysis, which requires data on at least five to eight oil tank fill-ups or gas meter readings to obtain an accurate picture of fuel consumption. The remaining 34 houses were analyzed with PRISM. Attrition in our PRISM analysis sample is more fully documented in Appendix D.

Data Analysis

Data analysis consisted of running one year of pre-weatherization fuel use records through the PRISM program. This program employs regression analysis in order to estimate "normalized annual consumption" (NAC -- an estimate of annual consumption under average weather conditions) as a function of outdoor temperature, balance point temperature, and average daily base fuel consumption (fuel consumption for uses such as cooking

and water heating which are not affected by changes in outdoor temperature).

Discussions with developers and experienced users of PRISM led us to statistically screen the PRISM equations and eliminate homes from the database which did not meet specified statistical criteria.[21] These tests eliminated an additional 11 homes from the database, leaving a maximum of 23 homes for which PRISM savings estimates can be made.

Using the PRISM equations for these houses, we attempted to estimate savings in two ways. First, we attempted to generate post-weatherization PRISM equations using weekly fuel consumption estimates derived from burner run-time meter data. Unfortunately, analyizing short-term space heating only data with PRISM produced poor-fitting regression equations, so attempts to compute fuel savings from these equations were stopped.[22]

Second, we input post-weatherization weather data into pre-weatherization PRISM equations for each house to produce a PRISM estimate of what fuel consumption would have been during the post-weatherization period if the weatherization work had not been done. These estimates were compared to actual post-weatherization fuel consumption during the same period, and savings were calculated. Savings were calculated on 19 homes in this manner including 15 house doctor homes. In the 15 house doctor homes, savings averaged 8.7% (with a standard error of 8.3%),[23] very close to the 8.9% average computed with the MAS's mean ratio

---

[21] Homes were eliminated from the analysis if the R2 was less than 90%, the covariance greater than 10%, or if the standard error for the reference temperature was undefined. The first two standards come from Dunsworth and Hewett, 1985. The last standard from Fels, Reynolds, and Stram, 1986.

[22] While Hirst and Goeltz (1986) were fairly successful at getting reasonable PRISM fits with short-term data, their analyses differed from our analyses in two important respects. First, their study metered the same energy uses for the two periods being studied. We attempted to compare total primary fuel consumption in one period, with submetered space heating fuel use in another period. Second, their short monitoring periods included approximately a month of data after the central heating system was turned off. Our monitoring periods included warm spring weather, but did not include extensive periods when the heating systems were shut off. For future studies which attempt to use PRISM to analyze data from short monitoring periods, comparison of the same type of metering data is essential, and extension of the monitoring period into the non-space heating season appears to be very useful. Use of PRISM on submetered data is also of questionable utility. See Dunsworth, Koehler, and Hewett (1986) for a discussion dealing with this issue.

[23] Most PRISM studies report standard errors instead of confidence intervals. A range of plus or minus two times the standard error is approximately equivalent to a 95% confidence interval.

method. This finding supports the validity of the savings estimates computed with MAS's mean ratio method. Estimates for several homes were extremely high or low (see Figure 7).[24] When the three highest and three lowest savings estimates are removed from the data base, savings in the remaining nine homes average 8.2% (with a standard error of 3.4%. PRISM derived savings figures for individual homes are summarized in Appendix B.2.

Attrition in the PRISM Sample

Of the 61 houses for which dealer records were sought, attrition in the oil heated houses totaled 81% while attrition in the gas heated houses was only 35%. These attrition rates should be taken into account when deciding on the initial sample size for PRISM studies. The attrition rate in oil heated homes calls into question the use of PRISM when examining oil heated low-income houses.

Conclusions and Recommendations

House Doctoring and Related Measures

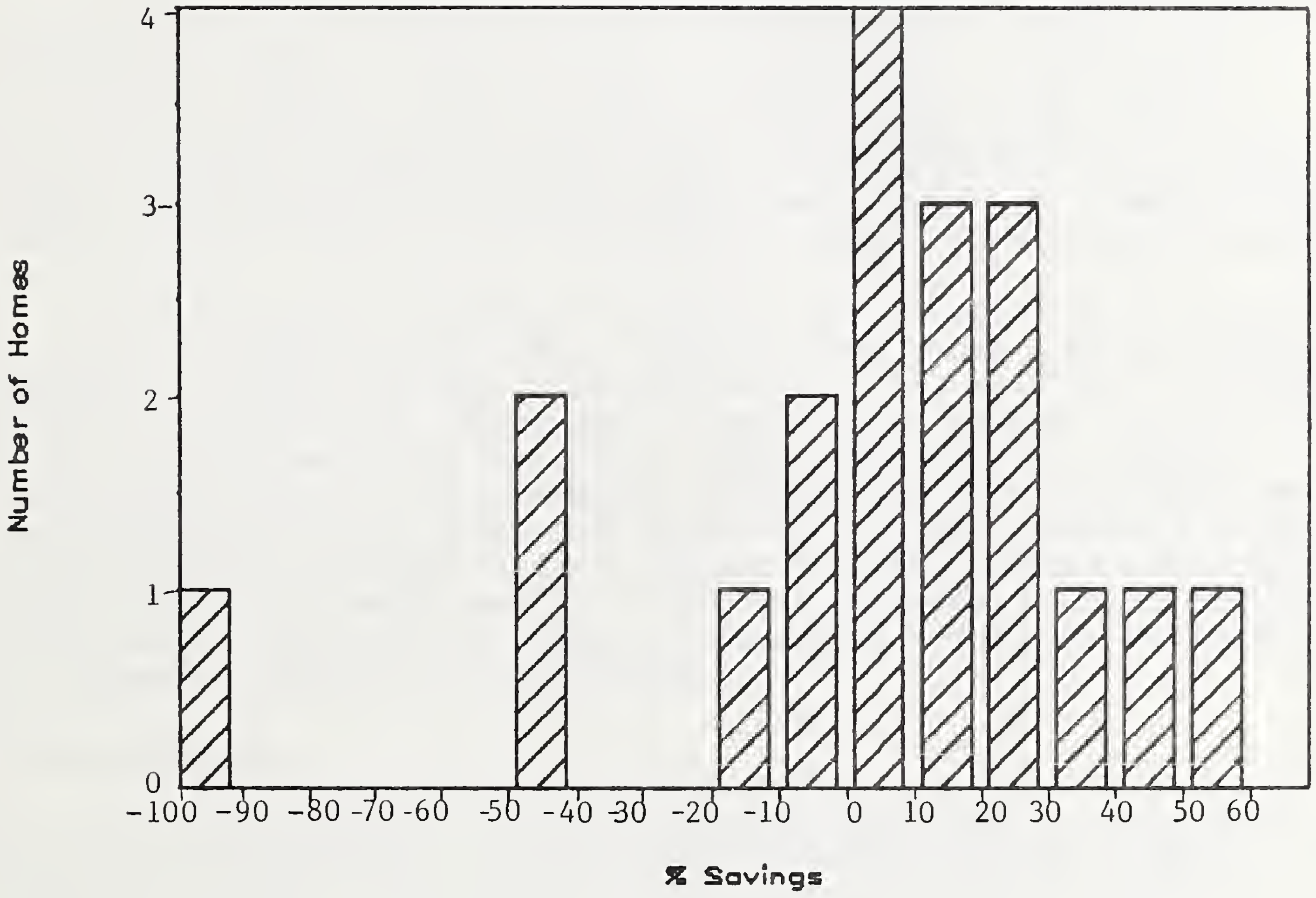
We recommend that house doctoring be a low priority weatherization measure in EOCD's energy conservation programs. House doctoring, as defined in this study, produced statistically significant energy savings. It proved to be cost-effective (benefit-cost ratio greater than one), but the benefit-cost ratio for house doctoring was lower than the overall ratio for EOCD's current weatherization programs.

We had hoped that some method could be developed to identify houses which can benefit most from house doctoring. Unfortunately, our research found that initial infiltration, as

---

[24] Most of these extreme estimates appear to be due to two factors. First, post-weatherization fuel consumption figures for some houses appear to be off due to errors in burner nozzle size and input rating records. These errors do not effect savings estimates with the MAS method (as long as the input rating does not change between the pre- and post-weatherization periods), but these errors do affect the PRISM-derived savings estimates. Second, PRISM is best at projecting total primary fuel use but less adept at estimating space heating only use. PRISM space heating only fuel consumption estimates are subject to considerable error. This problem is sometimes not significant when the full PRISM method is used, but the problem is exaggerated with the short-term variation on the PRISM method that we used. This problem could have been reduced in gas heated houses if we had recorded weekly gas meter readings. Another potential solution is to add a known artificial baseload to space heating data and then subtract this artificial baseload from the NAC estimates. Dunswoth, Koehler, and Hewett (1986) have used this approach.

Figure 7. Savings Distribution for PRISM Housedoctor Homes



measured with a blower door or assessed by an energy auditor, is a poor indicator of fuel savings performance. We encourage other researchers to investigate other potential screening methods.

While a thorough house doctoring job is only marginally cost-effective, the house doctoring contractors did find many large heat leaks in the houses they worked on. If conventional weatherization contractors spent a limited amount of time locating and sealing common leaks, we would expect that the savings would more than justify the cost. Auditors, crews and contractors working with EOCD energy conservation programs should be trained to identify and seal these leaks.

Living space caulking and weatherstripping (as practiced by contractor #2 and contractor #3 in this year's study and as studied in depth in last year's study) appear to increase occupants' comfort level. While living space caulking and weatherstripping is generally only marginally cost-effective, this measure should probably remain part of weatherization programs in houses with especially leaky windows and interiors, and in houses where comfort, and not only energy savings, is a primary concern.

Other aspects of house doctoring not studied in this project are also worthy of attention. One of the house doctor contractors employed in this project (contractor #1), in addition to plugging heat leaks, routinely does basic mechanical system adjustments, such as calibrating thermostats, balancing heating systems, installing low-flow showerheads, insulating water heaters, and checking furnace, boiler, and water heater set points. While this work was not included in this project (under instructions from MAS), these are important low-cost energy savers; EOCD should continue its efforts to make sure that this work is included in all houses served by its programs.

Storm Windows

MAS recommends that EOCD continue its current policy of making storm windows a low-priority weatherization measure. Storm windows are cost-effective energy savers, but given their relatively high cost, the fact that they are not always used properly, and the fact that they are exposed to the elements and deteriorate over time, they are not as cost-effective as many other weatherization measures. Generally, only after higher-priority weatherization measures have been undertaken should storm windows be considered. The exception to this rule is where a storm window will provide critical protection to a primary window. In these situations, it may be cost-effective to make a limited number of storm windows a medium priority weatherization measure.

Evaluation Method

The MAS fuel use analysis method used in this study provided a single-season determination of savings attributable to

particular weatherization treatments. The results obtained for the control group show that the data is probably not significantly influenced by extraneous factors. The results obtained using different analysis methods show that savings estimates do not change with changes in analysis method.

The MAS method is particularly valuable for studies of pilot programs (where results are needed quickly, so decisions can be made about whether to continue the pilot), for studies in homes where historical fuel usage records are unavailable (such as many oil heated homes), and for areas where extreme microclimate variations rule out the use of data from a weather station. The weakness of the method is the attention required from local agency personnel throughout the monitoring period. Future applications of this monitoring method should include greater centralization of work and/or working with a limited number of agencies which have personnel with the time and analytical skills necessary for such a project.

In this study we also attempted to use short-term variations on the PRISM method to estimate fuel savings. The high-attrition rate for oil heated homes calls into question the use of PRISM when examining low-income oil heated homes. For homes where fuel consumption records can be obtained, short-term variations on the PRISM method are difficult to do, but may have some potential.

Further Research Needed

EOCD has now sponsored three BirdWAP studies. These studies have examined the fuel savings of most of its existing energy conservation programs and of specific weatherization measures that are part, or may become part, of its programs. However, questions remain that additional research can help answer. In particular, we believe the following studies are needed:

(1) Investigate new weatherization measures such as controls to modulate boiler water temperatures (discussed in Nadel, Meyer, and Granda, 1986), and less comprehensive house doctoring procedures than were examined in this study.

(2) Study the fuel savings achieved by heating system replacements. Heating system replacement is the one major weatherization measure that EOCD regularly funds that it has not yet evaluated.

(3) Reexamine the fuel savings and cost-effectiveness of the overall WAP program. The WAP program has gone through considerable change since the 1984-85 BirdWAP study. Expenditure limits have been raised, priority lists changed, and extensive training programs run for auditors and contractors. Ideally, a WAP evaluation

Appendices

should look at fuel savings over several years in order to see whether savings are maintained over time.

(4) Start investigating weatherization measures appropriate for multi-family housing. EOCD weatherization programs and fuel savings studies have emphasized one to six unit homes. However, weatherization strategies for larger residential buildings are significantly different from the strategies employed in smaller buildings. Now that EOCD is starting several programs dealing with weatherization needs in multi-family housing, fuel savings evaluations on the programs and measures being tested would be useful.

(5) Inspect houses weatherized three to ten years ago to collect information on the actual lifetime of different weatherization measures. Material lifetime is a key factor in weatherization cost-effectiveness. However, no data on actual lifetimes has ever been collected. Collection of this data would improve the accuracy of cost-effectiveness determinations.

We believe these studies can help make EOCD's already excellent energy conservation programs even better.

Appendix A. Detailed Description of Methodology

This appendix contains a detailed explanation of the methodology and data analysis procedures used in the BirdWAP study.

Energy Uses Monitored

Fuel used for space heating was the focus of the study. While the EOCD energy conservation programs include measures to reduce fuel consumed for both space heating and water heating, this study investigated only space heating fuel consumption and savings. Space heating was the focus of this study because space heating accounts for the vast bulk of fuel use and savings in homes served by the EOCD energy conservation programs. Also, evaluating only the space heating component of fuel use kept the work load for this study to a manageable level.

Local Agency Selection

Eleven local WAP program operators were selected by EOCD to participate in this project. The local agencies chosen all had competent staff who could do a good job coordinating local work for the project. Agencies were also selected to provide a rural/suburban/urban balance and to provide geographic balance among the different regions in the state.

House Selection

Local agencies selected individual homes for monitoring using criteria developed by MAS. The selection criteria required that (1) each house or apartment be primarily heated with a single central system (no extensive use of space heaters, wood or coal stoves, or cooking stoves for space heating); (2) each heating system serve only the monitored apartment and no others; (3) households not use the same boiler to heat the living space and domestic hot water; and (4) each client be willing to cooperate with the monitoring study, which primarily required receiving a weekly phone call to collect meter readings. In addition, special requirements were imposed for two of the three study groups as is discussed in the body of the main report.

Fuel Consumption Data

A run-time meter was placed in series with the oil burner (for oil-heated homes) or the gas valve (for gas-heated homes). Inexpensive ($33 apiece) commercially available meters were used. Meters ran on 24 volts, ac. A small transformer assembly was used so the 24 volt timer could be powered by 115 volt current (for oil systems), 24 volt current (for most gas systems), or by millivolt current (for some gas systems). Oil meters were installed by licensed heating technicians. Gas meters were installed by either trained local agency personnel, or by licensed technicians.

Fuel consumption was calculated by multiplying the run time by the oil flow rate through the burner nozzle or the measured input rating of the gas burner. The oil flow rate was determined by backing out the burner and noting the nozzle size. According to Bernard Smith, Vice President for Operations of the New England Fuel Institute, oil flow should always be within 5% of the rated nozzle size (see Nadel, 1984b for a fuller discussion of this issue). The gas burner input rating was determined from the manufacturer's rating stamped on the name plate of the heating system. Over the course of this study, the nozzle size and input rating of all heating systems was not changed.

Temperature Data

The indoor/outdoor temperature difference was continuously monitored on-site using a moderate cost ($250) electronic temperature difference accumulator developed by MAS. This temperature difference data was used to adjust fuel consumption data to account for varying indoor and outdoor temperatures. The temperature difference accumulator continuously compares indoor and outdoor temperatures. This temperature difference is transmitted as a voltage to an electronic counter which increments the count at the rate of one unit per degree hour (Farenheit) of temperature difference (e.g. a 20 degree temperature difference for 2 hours equals 40 degree-hours). Recalibration of the accumulators after monitoring was completed showed them to be within 2% accuracy in all but a few cases.

The workings of the temperature difference accumulator are briefly described in the following paragraph: The temperature difference accumulator contains two temperature transducers (one placed inside the home, the other placed outside) which produce an output current proportional to the absolute temperature (1 micro amp/degree Kelvin). The two currents produced by the transducers are amplified and compared by a differential input instrumentation amplifier (one current is subtracted from the other) and fed to a voltage to frequency oscillator. At the oscillator the current is divided down to give the proper scaling factor between the input and the output. The oscillator gives off one pulse per degree hour (F) of temperature difference. These pulses are counted by a commercially available liquid crystal display.

In some cases, data from the accumulators was erratic, due to electrical, installation or user caused problems. In these cases, fuel consumption data was adjusted using degree-day data (base 60) from a nearby weather station. The statistical procedures used to locate erratic data are discussed in the "Data Analysis and Adjustment" section.

Monitoring Work

Houses were monitored for approximately six weeks before any weatherization work was done and then for approximately eight weeks after weatherization work was done. Fuel consumption and

temperature difference data were recorded on a weekly basis by local agency staff. Monitoring at each house began between mid-November, 1985 and New Year's, 1986. Monitoring at all houses was completed by late April, 1986 (April data was used only in the PRISM analyses; for all other analysis only data through the end of March was used since warm spring weather began in the first week of April).

Other Weather Data

New England Weather Service, a private weather consulting firm was hired to supply daily weather information for each of the communities included in the BirdWAP study. Data collected consisted of average outdoor temperature, number of hours during which the outdoor temperature exceeded 60 degrees F, average daily wind speed, and average % daily sun. New England Weather Service also provided long-term historic degree day information (base 60) for each of the communities. MAS calculated daily degree figures to a 60 degree F base using the average outdoor temperature data. Degree day figures were used to adjust fuel consumption figures when indoor-outdoor temperature difference data was erratic. Degree days were also used when projecting annual fuel bills. Information on hours above 60 degrees F was used to help determine when warm weather set in and data analysis should be cut off (at the point temperatures topped 60 degrees F during the majority of days during a week, data analysis was halted). This data was also used when adjusting temperature difference accumulator data as is described in the Data Analysis and Adjustment section below. Wind and sun data was used to determine if there were any systematic differences in these parameters between the pre- and post-weatherization monitoring periods that would significantly effect the fuel savings results.

Measurements and Questionnaires

Data on each house and the energy use habits of the occupants were collected before and after each monitoring period. These data included detailed measurements of each house, descriptive information on each house and its occupants and information on their living habits and changes in their living habits since the preceding monitoring period. This data was used to check if changes occurred in the area heated or in the use of supplemental heaters.

Data Analysis and Adjustment

All raw data was sent to MAS. Data was first examined for completeness and for problems noted on the post-monitoring questionnaires. Local agencies were contacted in an attempt to get missing information and to fully understand the problems that developed.

All fuel consumption and temperature data was entered into a data base management system set up by MAS using dBase III. The

first step in the analysis was to adjust temperature difference accumulator data to reflect the difference between the outdoor temperature and the balance point instead of the difference between the outdoor temperature and the indoor temperature. Since, according to classical engineering theory, energy use varies with the difference between the heating balance point and the outdoor temperature, we substracted 8° F/hour from the indoor/outdoor temperature difference data for each hour the outdoor temperature was above 60° F. This 8° F/hour adjustment was based on the assumption that the average indoor temperature in BirdWAP houses was 68° F (based on the results of a survey done as part of the 1984-85 BirdWAP study) and the average balance point temperature is approximately 60° F (based on research by Fels, 1985 and others).

Second, for each week of monitoring, the ratio of fuel consumption per degree hour and degree day was computed and then calculated as a percentage of the average ratio during the pre-weatherization period. For each house and each month, outlying data points were eliminated from the data base. Outlying points were defined as periods for which fuel consumption per degree hour (and degree day) differed by more than 20% from the mean of all weekly fuel consumption per degree hour (and day) figures for that house and that monitoring period.

Third, for each house and each monitoring period a T-test was run on fuel consumption per hour and fuel consumption per degree day figures. For houses and monitoring periods in which the T-tests on both the degree hour and degree day data showed there was at least a 20% chance the mean of the population could differ at least 20% from the mean of the sample, data for that house and monitoring period was eliminated from the data base.

The T-test data was also used to identify houses where degree hour data was erratic and needed to be replaced with degree day data. For houses for which the T values using the degree day figures were significantly higher than T values using the degree hour figures, degree day figures were used in subsequent analyses. In the final data base, degree day figures were used for about 25% of the houses. Analysis of average savings among houses in the BirdWAP study using both degree hour and degree day datasets, showed very similar savings.

A T-test on the difference between the means of the pre- and post-weatherization ratios was run on the final data base to figure the mean savings for each house and a 95% one-sided confidence interval about this mean. Analysis of variance (ANOVA) tests were conducted to calculate the mean savings for all houses served by a particular weatherization program and a confidence interval (95% one-sided) about this mean.

In addition to the analysis method discussed above (an analysis method we call the "mean ratio method," we also analyzed the data using linear regression analysis.

Regression Analysis

Pre-weatherization monitoring data were analyzed using linear regression techniques. For each house a best-fit equation was calculated of the form:

Fuel consumption = A * (degree hours) + B
where: fuel consumption comes from the burner timers,
degree hours from the temperature difference accumulator, and
A and B are the slope and intercept of the best fit line.

A similar equation was calculated for each house substituting degree day information from a local weather station for the degree hour data. Fuel savings were calculated by inserting post-weatherization degree hour (and degree day) information into the pre-weatherization regression equation in order to predict what fuel consumption would have been if no weatherization work had been done. This predicted consumption was then compared to actual post-weatherization fuel consumption data and savings calculated as a percent of predicted consumption without weatherization.

PRISM Analysis

PRISM (the Princeton Scorekeeping Method) is a sophisticated linear regression based fuel savings analysis technique that has been used extensively in other fuel savings studies. The PRISM method is described in other reports (see for example Fels, 1985). Some of the advantages and disadvantages of the PRISM method are discussed in Nadel and Meyer (1985). The PRISM method in its pure form requires approximately two years of fuel consumption information on each house -- one year prior to weatherization and one year post-weatherization. In addition the PRISM method requires outdoor temperature data from a local weather station.

For the BirdWAP study, we obtained one to two years of pre-weatherization fuel consumption data from each client's oil or gas company. We also obtained weather information for Boston and several other BirdWAP cities, from the National Climatic Data Center in Ashville, North Carolina. All houses for which we could get at least six actual (as opposed to estimated) fuel consumption readings were fed into the PRISM program for analysis. The PRISM program fits the data for each house into a best-fit linear equation of the form:

Fuel consumption = $A + B (T_{bp} - T_{out})$

where: A and B are the slope and intercept of the best-fit line,

T_{bp} is the balance point temperature for that house (estimated by PRISM), and

T_{out} is the average daily outdoor temperature for a nearby weather station over each monitoring period being analyzed.

PRISM also calculates a Normalized Annual Consumption (NAC) figure for each house as follows:

NAC = $(365 * A) + (B * DD_{tbp})$

where: DD_{tbp} is heating degree days (base T_{bp}) in a "typical" year.

NAC is an estimate of annual consumption in a house in a "typical" year. In addition to calculating NAC, PRISM calculates a correlation coefficient (R^2) for each regression equation and standard errors for NAC, A, B, and T_{bp}. The correlation coefficient and standard errors are statistical indices which measure how well the calculated values fit the actual fuel consumption patterns of each house). Houses which had a correlation coefficient of less than 90%, a standard error for NAC of over 10%, or a standard error for T_{bp} which was undefined were eliminated from our PRISM dataset. These data quality standards were recommended by the developers (Fels, Reynolds and Stram 1986) and experienced users (Dunsworth and Hewett, 1985) of PRISM.

Using the PRISM equations for these houses, we attemped to estimate savings for the remaining houses, even though we did not have a full year of post-weatherization fuel consumption data. Two variations on the pure PRISM method were employed in these attempts to estimate fuel savings using only two months of post-weatherization fuel consumption data.

First, we attempted to generate post-weatherization PRISM equations using weekly fuel consumption figures derived from burner run-time meter data. Unfortunately, analyzing short-term space heating only data with PRISM produced poor-fitting regression equations, so efforts to compute fuel savings from these equations were dropped.

Second, using a technique similar to the one described above in the Regression Analysis section, we input post-weatherization weather data into pre-weatherization PRISM equations for each house to produce an estimate of what fuel consumption would have been if the weatherization work were not done. These estimates were compared to actual post-weatherization fuel consumption during the same period and savings calculated as a percent of predicted consumption without weatherization.

Economic Analysis

Economic information on each program, including annual fuel dollars saved, simple payback period, and benefit-cost ratio, were compiled. Annual fuel dollars saved were estimated for each house using fuel consumption, degree day, and fuel savings data for that house, and fuel price and annual degree day information for each region. Pre-weatherization annual fuel cost for each house was estimated by taking total fuel consumption per degree day during the pre-weatherization monitoring period, and multiplying this figure by the average annual degree days for that community and the average price in Massachusetts for that fuel during the 1985-86 heating season ($1.00/gal. oil, $.70/therm gas). Fuel dollars saved in each house were estimated by multiplying the estimated pre-weatherization fuel bill for each house by the fuel savings figure for that house. For example, if 20% fuel savings were measured in a house, the fuel dollar savings were estimated by multiplying the pre-weatherization fuel bill by 0.2.

Benefit-cost ratios were calculated in an attempt to compare the benefits of different programs over the useful life of the weatherization improvements. Benefits were calculated by multiplying the average annual fuel savings achieved by each program by the estimated average lifetime of weatherization improvements made under that program (estimated lifetimes for each program are discussed in the section on each program in the main report). Benefit-cost ratios were then calculated by dividing average material and labor costs for each program into the lifetime benefits for that program. Implicit in these calculations was the assumption that fuel price inflation and the appropriate discount rate are identical.

Indoor Temperatures

Indoor temperatures were estimated using data from the temperature difference accumulators and from nearby weather stations. For each house, for both the pre-weatherization and post-weatherization monitoring periods, average indoor-outdoor temperature difference was calculated by dividing the number of hours in that monitoring period into the sum of the temperature difference data for that period. Average outside temperature for the same dates was calculated using information from a nearby weather station. Average indoor temperature for each house, for each monitoring period, was then estimated by adding the average outdoor temperature for that house and period to the average indoor-outdoor temperature difference for that house and period.

Appendix B.1. Basic Savings and Descriptive Data

Group	Fuel Savings % ± %		ACPH (50Pa)		Agency Eval.	Projected Annual Pre-treatment Heating Fuel Bill ($)	Heating Fuel Bill Per Degree Day ($)	Total Living Area (ft2)	Data Points		House #
			before	after					pre	post	
C	5.1	8.3			S	344	0.07	773	9	5	59
C	8.4	0.0			L	408	0.08	836	8	7	60
C	3.9	4.7			L	827	0.16	1493	8	6	61
C	-5.5	5.6			S	599	0.11	1215	9	5	64
C	9.4	8.4			S	366	0.07	750	6	8	74
C	-9.1	7.9			L	852	0.17	732	6	6	75
HD	9.2	4.5	28.1	24.8	S	1393	0.28	1187	6	8	38
HD	22.8	6.0	16.2	12.7	L	632	0.12	977	7	6	40
HD	1.7	0.0	17.3	15.3	S	814	0.17	859	6	9	42
HD	5.2	5.1	16.3	11.9		652	0.10	925	5	8	10
HD	2.0	5.5	15.9	11.0		991	0.15	1489	6	7	11
HD	4.9	4.5	16.5	11.5		1017	0.17	854	7	7	13
HD	4.8	0.0	7.0	5.8	L	813	0.19	1077	6	9	15
HD	-0.4	6.2	12.0	10.8	S	550	0.13	895	4	7	18
HD	6.0	7.8	12.0	10.8	S	361	0.09	895	2	5	19
HD	4.8	5.3	11.2	8.5	S	755	0.16	878	6	8	20
HD	0.8	11.6	15.3	12.0	M	1047	0.25	841	4	8	23
HD	6.3	0.0	15.3	12.0	M	722	0.17	870	7	8	25
HD	8.2	3.1	30.7	28.0	S	1021	0.21	788	5	8	32
HD	12.9	8.5	23.5	19.4	M	1041	0.19	1403	3	5	35
HD	25.6	10.8	15.1	11.2	L	829	0.13	929	8	5	49
HD	3.3	6.6	21.0	16.0	S	1283	0.20	766	7	4	50
HD	19.4	4.5	8.9	7.7		924	0.16	1273	7	5	51
HD	4.8	8.1	11.4	10.2	L	637	0.10	1019	8	6	52
HD	8.7	4.1	21.2	18.4	M	479	0.07	690	8	5	53
HD	2.9	10.3	10.2	7.6		595	0.09	1120	2	5	54
HD	14.4	3.5	23.2	15.7	S	913	0.19	684	7	7	68
HD	5.4	12.3	6.8	5.2	S	1174	0.22	1733	8	4	36
HD	22.8	8.5	15.7	9.6	M	516	0.11	1140	7	6	45
HD	11.5	10.0	7.9	5.6	L	376	0.08	1770	6	5	46
HD	4.8	5.3	11.1	7.2	M	481	0.11	1150	6	5	47
HD	11.2	11.4	18.3	10.0	M	1265	0.26	1775	5	3	48
HD	16.0	6.6	14.4	10.8	L	494	0.10	969	7	5	55
HD	11.7	5.5	27.4	12.5	L	553	0.12	845	10	4	56
HD	5.9	0.0	9.6	8.1	M	1258	0.24	1566	0	5	57
SW	1.0	13.4				1224	0.25	1059	5	3	1
SW	9.0	11.9			M	582	0.12	1380	5	6	3
SW	10.8	2.9			S	1158	0.24	1331	6	6	4
SW	12.7	21.8			S	956	0.20	1535	4	2	5
SW	14.5	9.8			S	2001	0.41	1536	7	3	8
SW	20.6	8.8			S	945	0.21	1710	5	6	9
SW	3.4	11.4				961	0.14	1425	6	4	12
SW	6.9	12.0			M	868	0.19	750	7	5	16
SW	16.7	0.0			M	1514	0.28	1327	6	9	34

Group: Control; House Doctor; Storm Windows
ACPH: Air Changes Per Hour (in Pascals)
Agency Evaluation: air exchange compared to a "typical" house
Less; Same; More
Fuel Bill: pre-treatment projected annual bill using $1/gallon and $.70/therm
Living Area: heated and unheated living area space

Appendix B.2. Savings Results Using Other Data Analysis Methods

		FUEL SAVINGS (%)					Pre-Weatherization Period R^2		
	House	Regression Method		Mean Ratio Method		Short Term	Submetered Fuel Data		Fuel Co. Data
Group	#	w/TDA	w/DD	w/TDA	w/DD	PRISM	w/TDA	w/DD	PRISM
C	28		-4.5		0.3 ± 9.4			1.00	
C	29		1.5		4.8 ± 9.2			0.93	
C	31		51.9		67.3 ± 7.9			0.96	
C	59	-106.1	0.6	-54.3 ±12.7	-6.1 ±12.7	28.9	0.05	0.92	1.00
C	60	28.2	20.4	3.9 ±13.1	16.5 ± 7.3	0.2	0.97	0.97	1.00
C	61	2.6	-1.6	3.9 ± 4.7	0.1 ± 3.9	6.9	0.87	0.88	1.00
C	62	41.2	51.1				0.03	0.65	
C	64	-17.9	23.5	-10.3 ± 7.2	17.2 ±10.4		0.75	0.88	
C	66						1.00	1.00	1.00
C	73	16.4	-9.2	7.8 ±15.9	-0.7 ± 8.4		0.92	0.99	
C	74	7.7	6.7	9.4 ± 8.4	6.5 ± 8.1		0.55	0.60	0.86
C	75	-11.8	-3.6	-9.1 ± 7.9	-37.3 ±15.6		0.03	0.77	
C	76			-10.5 ±22.8	-27.3 ±25.3				0.78
HD	10	5.4	5.5	5.2 ± 5.1	5.5 ± 7.1	27.8	0.95	0.88	0.96
HD	11	3.1	-3.4	2.0 ± 5.5	-5.7 ± 9.6		0.97	0.93	
HD	13	5.0	3.8	4.9 ± 4.5	2.7 ± 5.1		0.98	0.98	0.88
HD	15	4.7	4.6	4.8 ±	6.5 ±	-49.9	0.97	0.97	0.97
HD	18	-4.1	-7.7	-0.4 ± 6.2	-5.6 ±12.3	-16.3	0.96	0.99	0.98
HD	19	-73.6	-8.8	6.0 ± 7.8	-13.4 ±16.4	10.4	1.00	0.97	0.99
HD	20	7.0	4.5	4.8 ± 5.3	3.1 ± 5.9	-4.1	0.97	0.97	0.93
HD	23		3.9	0.8 ±11.6	5.0 ±10.8		0.98	0.96	
HD	25	6.2	12.8	6.3 ±	12.0 ±10.6	-97.3	0.91	0.92	0.99
HD	32	10.1	-1.6	8.2 ± 3.1	4.4 ± 9.6	-9.3	1.00	0.99	1.00
HD	33	46.7	45.6	39.1 ±	36.4 ±		1.00	1.00	0.94
HD	35	11.3	2.8	12.9 ± 8.5	5.8 ±15.3		1.00	1.00	
HD	36		5.4		5.4 ±12.3			0.93	0.89
HD	38	8.1	6.8	9.2 ± 4.5	6.6 ± 3.9	-45.7	0.98	0.90	0.99
HD	40	22.6	10.0	22.8 ± 6.0	9.1 ± 7.0		0.96	0.86	
HD	41	64.5	61.5	61.6 ±17.1	61.2 ± 5.5		0.11	0.99	
HD	42	5.1	10.4	1.7 ±	9.5 ±		0.84	0.85	
HD	45	22.1	12.1	22.8 ± 8.5	17.2 ± 9.0	35.0	0.94	0.95	1.00
HD	46		15.2		11.5 ±10.0	57.3		0.17	0.93
HD	47		5.5		4.8 ± 5.2	44.7		0.98	0.98
HD	48	13.1	16.0	11.2 ±11.4	15.9 ± 4.7		0.56	0.95	
HD	49	27.5	31.7	25.6 ±10.8	30.0 ±11.1		0.74	0.80	
HD	50	-19.6	3.9	-17.2 ± 6.7	3.3 ± 6.6		0.99	0.98	0.97
HD	51	23.2	19.7	23.5 ±10.4	19.4 ± 4.5		0.93	0.96	
HD	52	4.5	3.2	4.8 ± 8.1	2.7 ± 6.2		0.97	0.96	
HD	53	9.9	-1.8	8.7 ± 4.1	-1.4 ± 7.0		1.00	0.97	0.51

Group: C - Control; HD - House Doctor; SW - Storm Windows

		FUEL SAVINGS (%)					Pre-Weatherization Period R²		
	House	Regression Method		Mean Ratio Method		Short Term	Submetered Fuel Data		Fuel Co. Data
Group	#	w/TDA	w/DD	w/TDA	w/DD	PRISM	w/TDA	w/DD	PRISM
HD	54	37.2		2.9 ±10.3		12.3	1.00		0.97
HD	55	14.1	16.5	16.0 ± 6.6	15.6 ± 8.2	24.5	0.95	0.66	0.99
HD	56	10.3	8.7	11.7 ± 5.5	10.1 ± 5.9	10.0	0.98	0.98	0.99
HD	57	19.3	6.1	19.1 ±17.9	5.9 ±		0.86	0.83	
HD	65		-1.5		-2.4 ± 7.0			0.99	
HD	68	14.9	19.6	14.4 ± 3.5	20.0 ± 3.4	13.6	0.99	1.00	0.95
HD	71	74.2	72.6	73.3 ±10.8	73.4 ±18.2		0.99	0.85	0.97
SW	1	-12.3	-8.5	-3.0 ±18.8	1.0 ±13.3		0.33	0.40	0.97
SW	3	4.3	11.3	9.0 ±11.9	14.6 ± 8.3		0.41	0.71	
SW	4		10.6		10.8 ± 2.9			0.99	
SW	5		17.1		12.8 ±21.7			0.97	
SW	8	9.4	17.8	14.5 ± 9.9	16.7 ±10.3		0.99	0.98	
SW	9	20.3	20.6	20.6 ± 8.8	18.7 ± 9.8		0.93	0.89	
SW	12		7.1		3.3 ±11.4			0.92	
SW	16		7.3		6.9 ±11.9			0.71	
SW	22		82.3		82.6 ±12.9			0.21	
SW	24	11.1	63.6	18.9 ±14.8	65.6 ±14.7		0.99	0.99	
SW	34	19.6	5.3	16.7 ±	15.8 ± 8.6		0.86	0.80	
SW	39		0.5		-0.5 ± 7.2			0.51	
SW	58	42.7	45.1	44.9 ± 8.2	47.2 ±10.0		0.95	0.81	0.96
SW	63	12.8	11.8	11.0 ±	9.3 ±	2.6	0.94	0.82	0.99
SW	67						1.00	1.00	0.53

Group: C - Control; HD - House Doctor; SW - Storm Windows

Appendix B.3. Indoor Temperatures

		Indoor Temperature (°F)			
		Calculated		Self-Reported	
Group	House#	Pre	Post	Pre	Post
C	27			66.0	
C	30			64.7	
C	31			70.0	
C	37			69.0	
C	59	70.1	69.9	64.8	65.2
C	60	72.1	73.4	69.7	69.7
C	61	69.1	70.0	65.0	65.3
C	62			62.0	62.0
C	64	66.4	65.6	63.2	62.5
C	66			64.3	62.3
C	74	71.3	71.6	67.0	62.7
C	75	66.5	65.0	66.0	68.0
HD	10	73.1	72.2	70.0	68.0
HD	11	76.7	78.1	70.7	65.0
HD	13	72.7	72.3	70.5	67.1
HD	15	70.1	70.0	64.0	61.0
HD	18	76.3	76.7	70.0	68.0
HD	19	74.7	77.0	68.0	69.0
HD	20	74.5	74.3	66.2	65.0
HD	23	72.5	72.2	66.7	66.5
HD	25	72.0	72.0	64.3	70.0
HD	32	72.3	72.3	69.0	69.0
HD	33			68.0	72.0
HD	35	72.3	69.7	58.8	70.0
HD	36	31.1	69.2	63.3	66.2
HD	38	74.0	74.6	66.0	66.0
HD	40	70.1	73.6	68.3	69.3
HD	41			68.0	68.0
HD	42	74.1	70.5	68.0	68.0
HD	43			68.0	
HD	45	73.6	74.6	65.5	67.3
HD	46	64.8	99.9	58.1	54.7
HD	47	73.5	74.2	70.0	72.0
HD	48	68.0	66.4	65.0	63.3
HD	49	75.5	73.6	67.3	65.5
HD	50	63.0	58.4	68.7	66.0
HD	51	68.4	69.9		
HD	52	72.5	72.0		55.0
HD	53	75.2	86.7	66.7	66.7

Group: **C** - Control; **HD** - House Doctor; **SW** - Storm Windows

		Indoor Temperature (°F)			
		Calculated		Self-Reported	
Group	House#	Pre	Post	Pre	Post
HD	54	87.8	78.6		
HD	55	65.9	67.3	69.7	68.6
HD	56	68.8	69.1	68.0	66.7
HD	57	72.5	76.9	67.0	65.3
HD	65			70.0	65.3
HD	68	54.0	55.1	72.0	66.2
HD	71			62.5	63.5
HD	72			68.8	67.0
SW	1	70.1	67.7		
SW	3	74.5	74.8	69.0	68.0
SW	4	73.2	58.8	70.7	68.0
SW	5	66.1	45.4	67.2	66.5
SW	7			64.3	60.0
SW	8	74.7	71.9	67.8	68.0
SW	9	81.0	79.2	65.0	65.0
SW	12	74.0	62.8	64.7	62.0
SW	16	75.4	52.5	70.0	68.0
SW	22			65.0	
SW	24			70.0	70.0
SW	34	84.1	81.1	70.0	70.0
SW	39	77.5	99.9	68.0	68.0
SW	58			71.0	68.7
SW	63	72.6	72.3	68.0	68.0
SW	67			62.7	

Group: **C** - Control; **HD** - House Doctor; **SW** - Storm Windows

Appendix C. Houses Dropped From Final Sample

#	Group	Explanation
27	C	Meters removed by agency at end of baseline period
28	C	" "
29	C	" "
30	C	" "
31	C	" "
37	C	Received burner tune-up at end of baseline period
62	C	Data failed T-test
66	C	Meters never installed correctly; millivolt system
73	C	Meters not installed until late January
76	C	" "
41	HD	Used heater on gas stove for much of heat
43	HD	Contractor couldn't complete work; structural problems
33	HD	Insulation work done by client during study
70	HD	Agency removed house from study to proceed with weatherization; no housedoctor work done.
71	HD	Burner timer broke during follow-up period
72	HD	Meters never installed correctly
44	HD	Client hospitalized; no house doctor work
65	HD	Client home days follow-up period; TDA broken
2	SW	Storm windows installed in June due to curved sashes
6	SW	Insulation work by other agency shortly after treatment
7	SW	Often out of oil second period; heated with stove
14	SW	Client evicted
17	SW	Client moved out
21	SW	Landlord insulated building
22	SW	Meters never installed correctly; milivolt system
23	SW	Data failed T-test
26	SW	Landlord insulated building
58	SW	Client infrequently home follow-up period; TDA broken
67	SW	Data failed T-test
69	SW	Client refused to report follow-up period readings

C - Control Group
SW - Storm Window Group
HD - House Doctor Group

Appendix D. Results of PRISM Data Search

Oil	Gas	
45	31	Initial Study Homes
	6	Other weatherization work
	1	Evicted during study
	1	Moved out during study
1		House unsafe - dropped from study
1		Client hospitalized - dropped from study
2	8	No dealer records sought
4		No steady fuel dealer
1		New occupant
6		No information provided (after 2 letters, 1 phone call)
8		COD oil companies - records not kept
1	4	Fuel dealer didn't maintain reading dates
20	4	Inadequate dealer records
4		All fixed level deliveries in 1985
2		Client changed dealers during 1985
1	1	Only 2 readings for 1985
7	1	Too few data points on customer
16	18	Houses analyzed
6	3	R-squared less than 90%
2	0	Covariance greater than 10%
8	15	Final sample
18%	48%	% of initial study homes
19%	65%	% of records sought

Appendix E. Questionnaires and Responses

MAS/EOCD WEATHERIZATION FUEL SAVINGS STUDY HOME INFORMATION QUESTIONNAIRE

AGENCY:_______________ JOB # :__________________
DATE: __/___/8___ CLIENT:__________________
GROUP: HD SW C ADDRESS:___________ ________
PERSON COMPILING DATA:______________________________

---

1. Unit occupied by	OWNER RENTER
2. Number of units in building	1 2 3 4+
3. Age of building (in years)	_10 _20 _30 _40 _50 _60 _70 _80 _90 100
4. Number of floors in monitored unit	1 2 3 4
5. Number of heated rooms in monitored unit	1 2 3 4 5 6 7 8 9 10 11 12 ___
6. Number of unheated rooms (closed off)	0 1 2 3 4 5 6 7 8 ___
7. Does client receive Fuel Assistance?	YES NO
8. Heat distribution system	STEAM/HOT WATER/HOT AIR/OTHER
9. Year of last tune-up	19____ UNKNOWN
10. Primary heating fuel	OIL/NATURAL GAS/BOTTLED GAS
11. Secondary heat source	NONE/SPACE HEATER/STOVE/OTHER
12. Fuel source for water heating	ELECTRIC/OIL/NATURAL GAS/BOTTLED GAS
13. Type of water heater	FREESTANDING TANKLESS
14. Temperature setting on water heater	HIGH MEDIUM LOW ____F
15. Cooking fuel	ELECTRIC/OIL/NATURAL GAS/BOTTLED GAS
16. Stove ignition (gas only)	PILOT LIGHT/MATCHES/ELECTRIC
17. Number of hours stove is used daily	0 1 2 3 4 5 6 7 8 ____
18. Number of appliances in household	
18a. Refrigerator-Freezer	0 1 2 ___
18b. Refrigerator	0 1 2 ___
18c. Freezer	0 1 2 ___
18d. Room air conditioner	0 1 2 3 4 _____
18e. Television	0 1 2 3 4 _____
18f. Dishwasher	0 1 2 ___
18g. Washing Machine	0 1 2 ___
18h. Gas Clothes Dryer	0 1 2 ___
18i. Electric Clothes Dryer	0 1 2 ___
19. Number of washing machine loads per week	0 1 2 3 4 5 6 7 8 9 10 11 ___
20. Water temperature usually used in washer	COLD WARM HOT

PLEASE COMMENT ON ANY UNUSUAL ANSWERS:

MAS/EOCD WEATHERIZATION FUEL SAVINGS STUDY HOME INFORMATION QUESTIONNAIRE

		76 INITIAL HOMES	46 FINAL HOMES
1. Unit occupied by			
	OWNER	48 (63%)	32 (70%)
	RENTER	28	14
2. Number of units in building			
	ONE	47	32
	TWO	18	3
	THREE	9	1
	FOUR+	2	0
3. Age of building (in years)			
	OLDEST	150	150
	AVERGE	70.2	66.3
	NEWEST	20	20
4. Number of floors in monitored unit			
	AVERAGE	1.6	1.7
5. Number of heated rooms in monitored unit			
	AVERAGE	6.5	6.7
6. Number of unheated rooms (closed off)			
	AVERAGE	0.5	0.5
7. Does client receive fuel assistance			
	NUMBER	64 (84%)	39 (85%)
8. Heat distribution system			
	HOT AIR	39	24
	HOT WATER	21	9
	STEAM	10	8
	NO RESPONSE	6	5
9. Last heating system clean-out			
	1984-PRESENT	45	28
	1975-1983	6	6
	UNKNOWN/NO RESPONSE	25	12
10. Primary heating fuel			
	OIL	45 (59%)	29 (63%)
	GAS	31	17
11. Secondary heat source			
	YES	13	6
	NO	60	38
	NO RESPONSE	3	2

12. Fuel source for water heating			
	GAS	53 (73%)	32 (73%)
	OIL	4 (5%)	2 (5%)
	ELECTRIC	14 (19%)	8 (18%)
	BOTTLED GAS	2 (3%)	2 (5%)
	NO RESPONSE	3	2
13. Type of water heater			
	FREE-STANDING HEATER	75	46
14. Water heater temperature setting			
	HIGH	2	2
	MEDIUM	53	33
	LOW	11	5
	NO RESPONSE	10	6
15. Cooking fuel			
	GAS	42	24
	ELECTRICITY	30	19
	BOTTLED GAS	3	3
	NO RESPONSE	1	0
16. Gas stove ignition			
	PILOT LIGHT	41	24
	MATCHES	1	1
	ELECTRONIC	3	2
17. Number of hours stove is used daily			
	AVERAGE (hours)	1.9	1.7
18. Number of appliances in household			
	REFRIGERATOR/FREEZER	75	43
	REFRIGERATOR	11	8
	FREEZER	22	16
	AIR CONDITIONER	25	16
	TELEVISIONS	139	81
	DISHWASHER	16	9
	CLOTHES WASHER	63	39
	ELECTRIC CLOTHES DRYER	24	15
	GAS CLOTHES DRYER	13	6
19. Number of washing machine loads per week (homes with washers only)			
	AVERAGE	6.0	5.2
20. Water temperature usually used in washer			
	HOT	0	0
	WARM	42	27
	COLD	20	11
	NO RESPONSE	1	1
21. Floor area (square feet)			
	AVERAGE HEATED	1048	1037
	AVERAGE TOTAL	1132	1131
	LARGEST TOTAL	3200	1775
	SMALLEST TOTAL	534	684

MAS/EOCD WEATHERIZATION FUEL SAVINGS STUDY POST MONITORING QUESTIONNAIRE

AGENCY:__________ JOB # :______
DATE: __/___/8__ CLIENT:______________
GROUP: HD SW C ADDRESS:________________
PERSON COMPILING DATA:______________ MONITORING PERIOD: I II

PLEASE ANSWER ALL QUESTIONS ONLY AS THEY PERTAIN TO EVENTS DURING THE MONITORING PERIOD	
1. How comfortable was the temperature in your home during the monitoring period	VERY COMFORTABLE FAIRLY COMFORTABLE FAIRLY UNCOMFORTABLE VERY UNCOMFORTABLE
2. Would you say your house has been	VERY DRAFTY / SOMEWHAT DRAFTY A LITTLE DRAFTY / NOT DRAFTY
3. How has your thermostat been set?	
3a. Morning	____degrees for _____ hours
3b. Daytime	____degrees for _____ hours
3c. Evening	____degrees for _____ hours
3d. Night	____degrees for _____ hours
4. Number of people living in your home	1 2 3 4 5 6 7 8 ____
5. Number of people at home on normal weekdays	0 1 2 3 4 5 _____
6a. Has anyone been ill for more than two days?	YES NO
PLEASE GO ON TO #7 IF YOU ANSWERED "NO"	
6b. By how many degrees did you raise the thermostat during this period?	0 1 2 3 4 5 6 7 8 9 10 _____
6c. For how many days?	0 1 2 3 4 5 6 7 8 9 10 _____
7a. Number of days house was unoccupied	0 1 2 3 4 5 6 7 ____
PLEASE GO ON TO #8 IF YOU ANSWERED "0"	
7b. Thermostat setting during this period	50 55 60 65 70 75 ____
8a. Did you use electric space heaters?	YES NO
PLEASE GO ON TO #9 IF YOU ANSWERED "NO"	
8b. Please list wattages and typical daily usage	_______watts ___hours _______watts ___hours _______watts ___hours
9a. Did you use an oven or wood or coal stove for space heating?	YES NO
PLEASE GO ON TO #10 IF YOU ANSWERED "NO"	
9b. Type of space heater used	OVEN / WOOD STOVE / COAL STOVE
9c. Typical daily usage	0 1 2 3 4 5 6 7 8 ___hours
10a. In how many rooms was heat shut off for at least half the monitoring period?	0 1 2 3 4 5 6 7 8 ____
PLEASE GO ON TO #11 IF YOU ANSWERED "0"	
10b. In which rooms?	______________________ ______________________ ______________________

	______________________________
11. Occurrences during monitoring period	
11a. Windows broken	0 1 2 3 4 5 6 7 _____
11b. Heating system breakdown (in days)	0 1 2 3 4 5 6 7 _____
11c. Holes in walls or roof	0 1 2 3 4 5 6 7 _____
11d. Other (please describe below)	
12. Changes in energy use habits	
12a. Guests staying more than three days	0 1 2 ___ PEOPLE FOR ___ DAYS
12b. Cooking	MUCH LESS/ NORMAL/ MUCH EXTRA
12c. Clothes washing	MUCH LESS/ NORMAL/ MUCH EXTRA
12d. Other (please describe below)	
13. TO BE ANSWERED BY PERSON ADMINISTERING QUESTIONNAIRE How much air do the windows and doors let in compared to those in a typical house	LESS / THE SAME / MORE

PLEASE COMMENT ON ANY UNUSUAL ANSWERS:

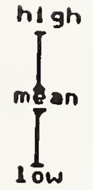
____

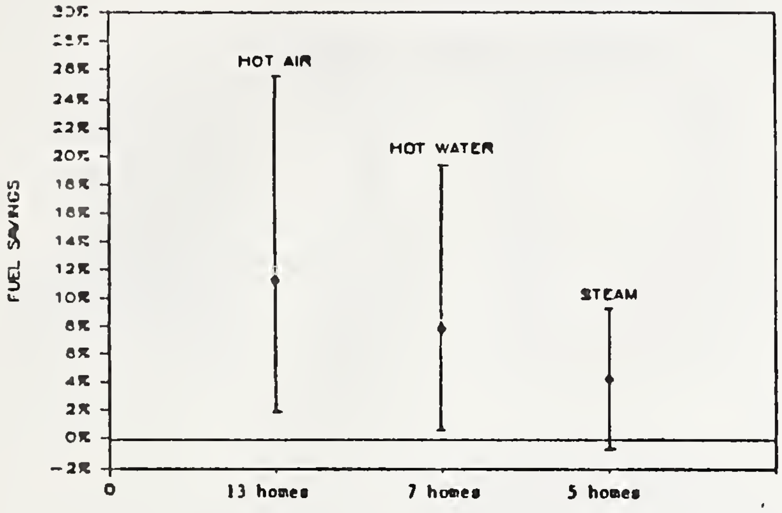
____

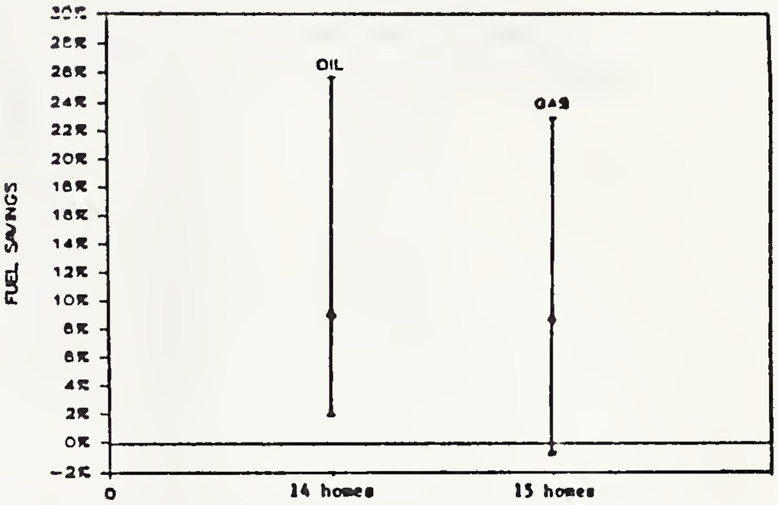
____

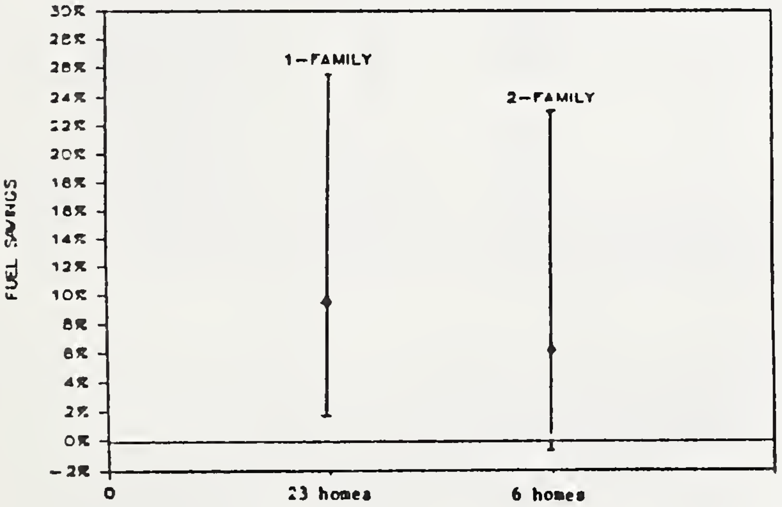
____

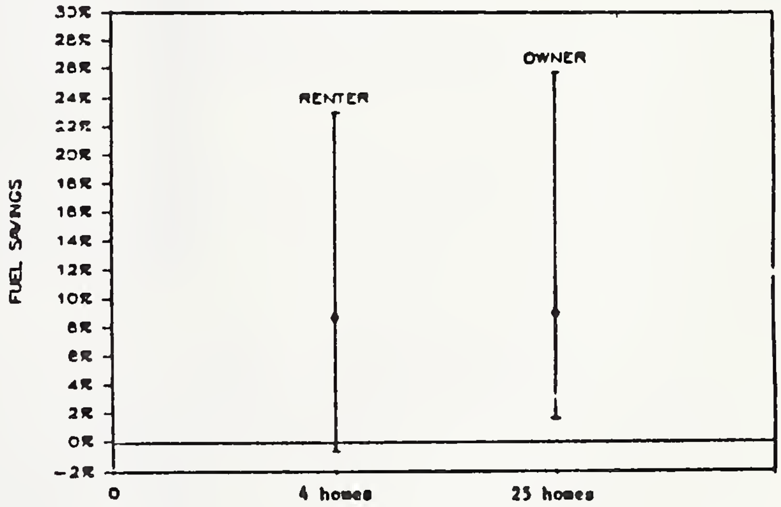
Appendix F. Additional Energy Savings Distribution Graphs

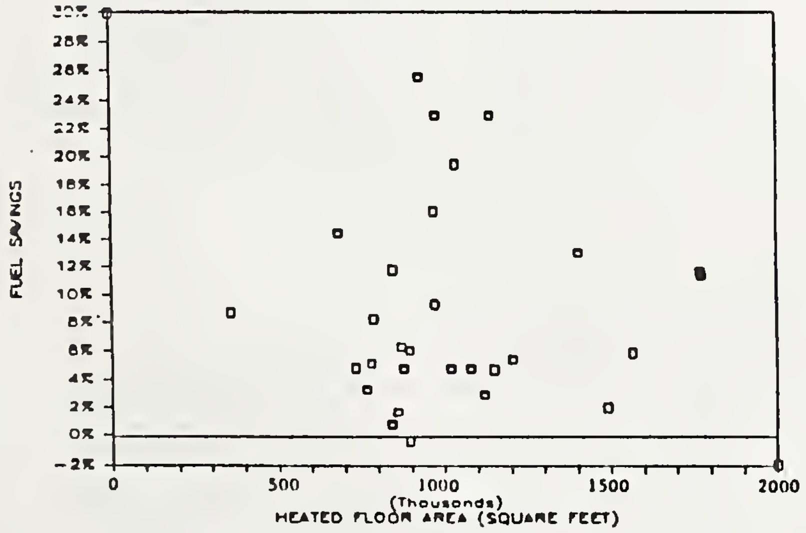


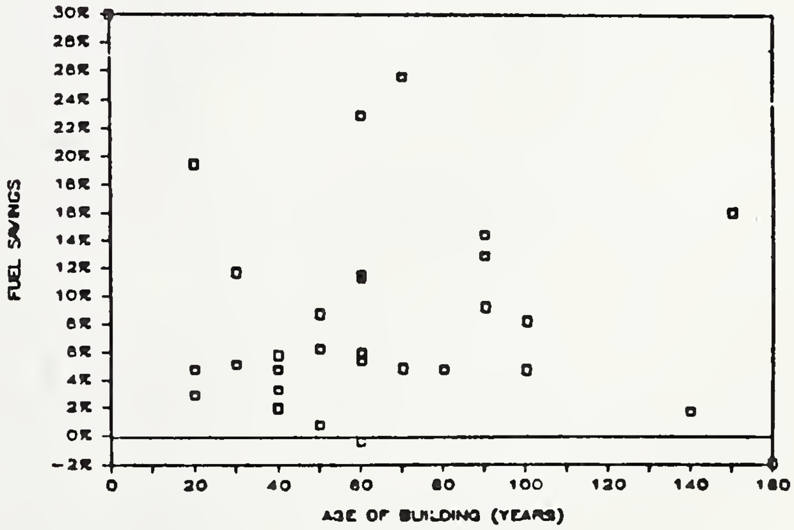












Appendix G. Monthly Weather Tables: December 1985 - March 1986

	Average Temperature					
	December	January	February	March	Entire Period	30 Year Average Annual Degree Days (60o base)
Arlington	30	30	28	40	32	4950
Boston	32	32	29	41	33	4866
Fall River	32	32	29	41	34	4630
Framingham	30	30	27	39	32	5398
Gardner	28	28	26	39	30	6438
Lawrence	29	28	27	39	31	5452
Peabody	30	30	28	39	32	5277
Pittsfield	27	26	26	38	29	6650
Springfield	30	29	27	40	32	5372
All	30	29	27	40	32	

	Average Wind Speed				
	December	January	February	March	Entire Period
Arlington	9	10	8	9	9
Boston	12	13	11	13	12
Fall River	12	13	11	13	12
Framingham	9	10	9	10	10
Gardner	9	10	9	10	10
Lawrence	10	12	10	12	11
Peabody	10	11	8	10	10
Pittsfield	10	11	9	11	10
Springfield	11	13	11	12	12
All	10	11	9	11	11

	Average Percent Sun				
	December	January	February	March	Entire Period
Arlington	47	58	51	62	55
Boston	48	58	50	62	55
Fall River	51	59	48	62	55
Framingham	48	60	48	62	55
Gardner	45	57	48	61	53
Lawrence	44	57	50	60	53
Peabody	48	58	50	61	54
Pittsfield	43	56	44	60	51
Springfield	52	62	47	63	56
All	47	58	48	62	54

	Hours Above 60 Degrees				
	December	January	February	March	Entire Period
Arlington	3	1	0	32	36
Boston	4	0	0	34	38
Fall River	5	1	0	15	21
Framingham	0	1	0	34	35
Gardner	0	0	0	33	33
Lawrence	2	0	0	28	30
Peabody	4	0	0	29	33
Pittsfield	0	0	0	29	29
Springfield	0	0	0	40	40
Average	2	0	0	30	33

Source: New England Weather Service

References

Anderson, Bruce, and M. Riordan, 1976, The Solar Home Book (Harrisville, N.H.: Cheshire Books).

Bliss, Steve, September 1984, "House Doctors with Better Medicine," Solar Age, pp. 27-31.

Commission on Economic Opportunity of Luzerne County, 1985, Analytical Weatherization Services Demonstration Project: Integrating House Doctoring into the Weatherization Program (Wilkes Barre, PA: Commission on Economic Opportunity).

Diamond, R.C., J.B. Dickinson, R.D. Lipshutz, B. O'Regan and B. Shohl, 1982, The House Doctor's Manual (Berkeley, CA: Energy Performance of Buildings Group, Lawrence Berkeley Laboratory).

Dickinson, J.B., D.T. Grimsrud, D.L. Krinkel, and R.D. Lipschutz, 1982a, Results of the Bonneville Power Administration Weatherization and Tightening Projects at the Midway Substation Residential Community (Berkeley, CA: Lawrence Berkeley Laboratory).

Dickinson, J.B., R.D. Lipschutz, B. O'Regan, and B.S. Wagner, 1982b, Results of Recent Weatherization Retrofit Projects (Berkeley, CA: Lawrence Berkeley Laboratory).

Dunsworth, Timothy S. and M.J. Hewett, 1985, "Data Quality Considerations in Using the Prism Program," in Energy Conservation Program Evaluation: Practical Methods, Useful Results, Proceedings, Volume I, August 19-21, 1985 (Argonne, IL: Argonne National Laboratory).

Dunsworth, Timothy S., M.J. Koehler and M.J. Hewett, 1986, "A Tale of Two Methods: Analysis of Energy Use Data From Multifamily Retrofit Tests," in Performance Measurement and Analysis, Proceedings, Volume 9, August 1986 (Washington, DC: American Council for an Energy Efficient Economy).

Dutt, Gautam, M. Levine, B. Levi, and R. Socolow, 1985, The Modular Retrofit Experiment: Design, Scorekeeping and Evaluation (Princeton, N.J.: Center for Energy and Environmental Studies, Princeton University).

Energy, Mines, and Resources Canada, 1984, Air Sealing Homes for Energy Conservation (Second Draft) (Ottawa, Ontario: Minister of Supply and Services).

Engels, Danielle, and H.G. Peach, 1985, "Real World Application: Field Testing the Value of House Doctoring as an Incremental Conservation Measure," in Energy Conservation Program Evaluation: Practical Methods, Useful Results, Proceedings, Volume I, August 19-21, 1985 (Argonne, IL: Argonne National Laboratory).

Fels, Margaret, 1985, The Princeton Scorekeeping Method: An Introduction (Princeton, N.J.: Center for Energy and Environmental Studies, Princeton University).

Fels, Margaret F., C.L. Reynolds and D.O. Stram, 1986, The Princeton Scorekeeping Method: Documentation for Heating-only Estimation Program, Version 3.0, (Princeton, N.J.: Center for Energy and Environmental Studies, Princeton University).

Harrje, D.T., G.S. Dutt, R.H. Socolow, K.J. Gadsby, and G.T. Linteris, 1980, "Beyond Twin Rivers: Energy Analysis and the House Doctor" (Princeton, N.J.: Center for Energy and Environmental Studies, Princeton University).

Hirst, Eric and R. Goeltz, 1986, Electricity Use for Residential Space Heating" Comparison of the Princeton Scorekeeping Method with End-Use Load Data (Oak Ridge, TN: Oak Ridge National Laboratory).

Kempton, Willett, and S. Krabacher, 1984, "Thermostat Management: Intensive Interviewing Used to Interpret Instrumentation Data," in Doing Better: Setting an Agenda for the Second Decade, Vol. F, ACEEE 1984 Summer Study on Energy Efficiency in Buildings (Washington, D.C.: American Council for an Energy-Efficient Economy).

Nadel, Steven, 1984a, Fuel Savings Achieved by the Weatherization Assistance Program in Two Massachusetts Communities: Report on the Weatherization Fuel Savings Study (Lincoln, MA: Massachusetts Audubon Society).

Nadel, Steven, 1984b, "Fuel Savings Achieved by the Weatherization Assistance Program: A New Fuel Savings Evaluation Methodology and Its Application to Programs Operated in Two Massachusetts Communities," in Energy Conservation Program Evaluation: Practical Methods, Useful Results, Proceedings, Volume I, August 27, 1984 (Argonne, IL: Argonne National Laboratory).

Nadel, Steven, and P. Meyer, 1985, "Timely Evaluations: A Method for Undertaking and Evaluating an Energy Conservation Program in Under One Year," in Energy Conservation Program Evaluation: Practical Methods, Useful Results, Proceedings, Volume I, August 19-21, 1985 (Argonne, IL: Argonne National Laboratory).

Nadel, Steven, P. Meyer and C. Granda, 1986, Fuel Savings Achieved by Massachusetts' Low Income Weatherization Programs: A Report on the BirdWAP Study (Lincoln, MA: Massachusetts Audubon Society).

Nadel, Steven, and M. Sherman, 1985, "A Comparative Evaluation of Six Different Energy Conservation Programs Serving Low-Income Households in Massachusetts," in Energy Conservation Program Evaluation: Practical Methods, Useful Results, Proceedings, Volume I, August 19-21, 1985 (Argonne, IL: Argonne National Laboratory).

O'Regan, B.C., B.S. Wagner, and J.B. Dickinson, 1982, _Results of the Walnut Creek House Doctor Project_ (Berkeley, CA: Lawrence Berkeley Laboratory).

Quaid, Maureen, T. Dunsworth and M. Hewett, 1986, "An Evaluation of the Community Energy Workshop: An Energy Conservation Pilot Program for Low Income Households" (Minneapolis, MN: Minneapolis Energy Office).

Rodberg, Leonard, 1986, "Energy Conservation in Low Income Homes in New York City: The Effectiveness of House Doctoring" (Queens, N.Y.: Department of Urban Studies, Queens College); in _Energy and Buildings_, 9(1), pp. 55-64.